DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

GEOLOGICAL SURVEY AND MUSEUM

BRITISH REGIONAL GEOLOGY

EAST ANGLIA

AND ADJOINING AREAS

(THIRD EDITION)

LONDON: HER MAJESTY'S STATIONERY OFFICE

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by

C. P. CHATWIN, M.Sc.

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FOREWORD
TO THE THIRD EDITION

Since the publication of the second edition of this Handbook, results in various fields of research connected with East Anglia have modified or superseded views previously held. Those modifications that are appropriate for the purpose of the Handbook have been incorporated, the chief subjects thus affected being the constitution of the Chalk, the boundary between the Pliocene and Pleistocene deposits, the distinction between the Chalky Boulder Clays and the origin of the Broads. A note has been made of the mixed character of the vertebrate faunas represented in the Cromer Forest Beds. The delineation of the area of the Crag on the Map (Frontispiece) has been adapted to the new Pliocene-Pleistocene boundary; and new figures (Fig. 31B and C) have been added to show the directions of ice-movement over the area.

Slight abridgement has been necessary in some sections of the text.

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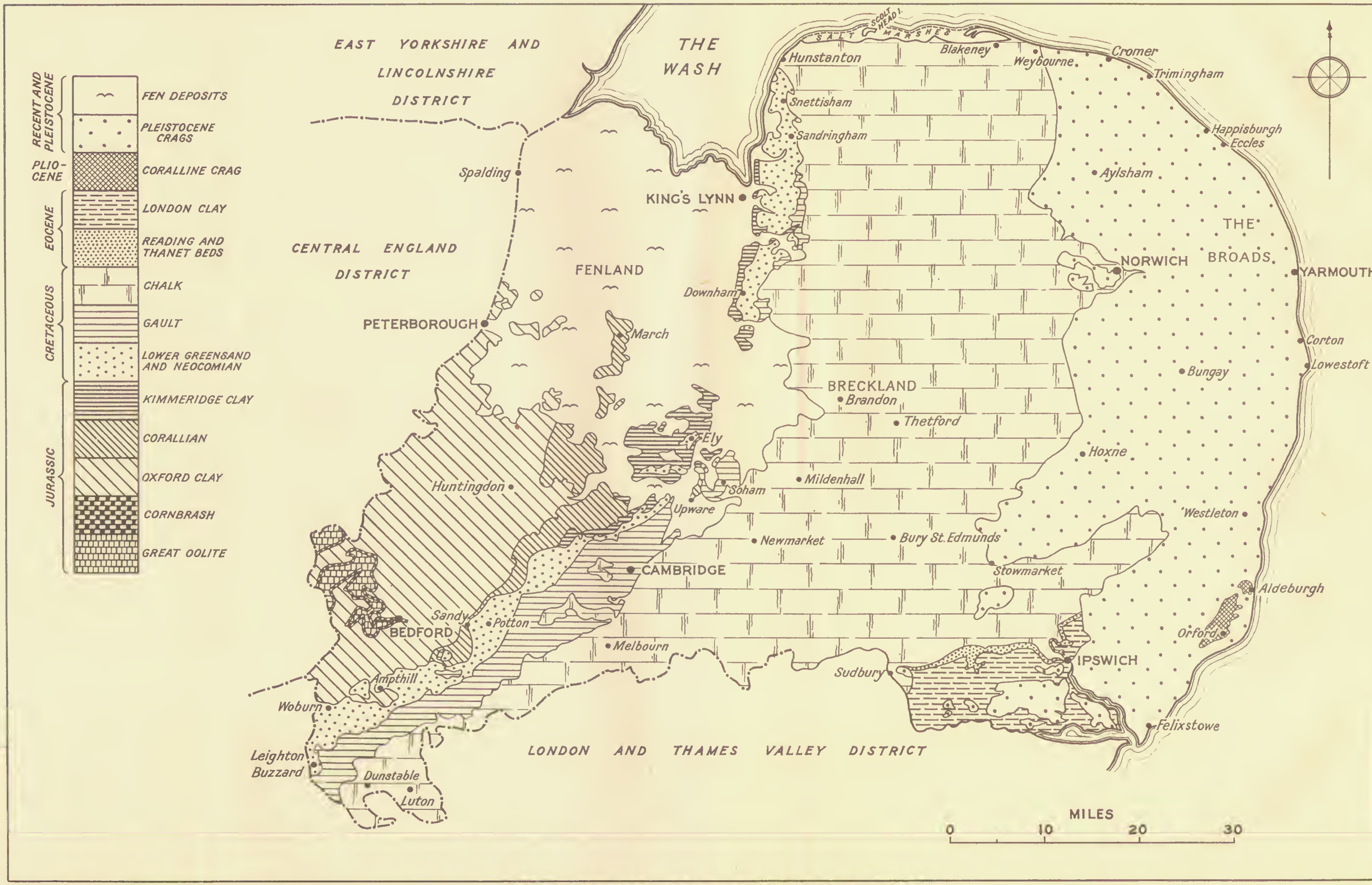

EAST ANGLIA AND ADJOINING AREAS

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EAST ANGLIA AND ADJOINING AREAS

I. INTRODUCTION

EAST ANGLIA, one of the kingdoms into which Anglo-Saxon Britain was divided, includes Norfolk and Suffolk, with a small area of the Fens of Cambridgeshire as its western boundary. As a geographical unit it is well defined and almost separate but for a tract of downland in the south-west, which connects it with the Chiltern Hills. Certainly it is lacking in bold natural features and affords no scenery that is arresting to the eye. Yet it has definite attractions that have become familiar through the paintings of Constable, Gainsborough, and the Norwich School and through the writings of George Borrow, who used his Jasper Petulengro to sigh for the charms of its heaths.

From the geological point of view, also, this part of our country contains definite units that merit separate description. Within its borders are strata that tell the history of the Pliocene and Pleistocene Periods as it is told nowhere else; and here also some of our earliest ancestors shared the land with strange beasts while the climatic fluctuations of the Ice Age were in progress. These two subjects alone would provide appropriate material for separate representation in a Museum.

When therefore in 1935, the project of illustrating the geology of Great Britain in the new Museum of the Geological Survey came to be considered, East Anglia was obviously one of the units into which the country was divided for this purpose. But arbitrary boundaries to the various divisions became necessary on account of limitations of space. Thus the area including East Anglia had to be extended westwards to meet the boundaries fixed for adjoining regions. As extended for the present purpose the region includes Bedfordshire, Cambridgeshire, Huntingdonshire, and a small part of south Lincolnshire, as well as Norfolk and Suffolk. To this region, as to other parts of Great Britain, one bay in the Museum has been allotted, and a representative series of specimens, photographs, and maps displayed.

In conformity with the treatment of material in the Museum cases, which is explained by labels appropriate for the general enquirer, this Handbook is designed to explain the geology of the country of which the Museum exhibits are illustrative; and it is prepared for the general reader, since detailed and technical accounts are included in the ordinary Memoirs of the Survey, which cover a large part of the region.

Most of the mapping and description of the country was done by the Geological Survey in the latter half of the last century, but the area has never ceased to attract the interest of other workers. From the earliest days of geological investigation the region under consideration has engaged the attention of geologists and those interested in the study of fossils, and a bibliography of all their publications would alone occupy more than the pages of this book.

Several factors have contributed to the advance of our knowledge of this region. Along its coasts are many popular holiday resorts, and the attention of generations of visitors has been attracted to the rocks that are readily accessible in the cliffs. Large numbers of rock-specimens and fossils have thus been collected and have found their way into museums and private collections, and many new to science have been duly made known in scientific literature. Famous holiday centres such as Hunstanton, Cromer and Felixstowe are well known in geological literature, while less-frequented places such as Weybourne, Trimingham, Mundesley and Eccles are equally familiar to the geologist. In like manner the economic value of many of the strata has caused extensive quarrying and excavating, in the process of which much material has been handled and many embedded fossils and rocks disclosed. Thus the digging of clays for brick-making, of chalk for lime-burning, and of other beds in search of ' coprolites ' for phosphates has brought to light a wealth of material that has been described and illustrated in scientific publications. The presence also of a flourishing school of geology in the University of Cambridge has been a great stimulus in the investigation of the area. Regular visits by parties of students to places of geological importance in the neighbourhood have resulted in many important finds, while specific subjects of research have been undertaken by teachers in this University.

So far as is possible with a large and varied area, an historical treatment has been adopted in this Handbook, since limitation of size precludes detailed description. Thus in dealing with the oldest rocks first, we begin with the Jurassic beds in the west, by reason of the arrangement of the strata. Rocks of this age in Cambridgeshire were described by Thomas Roberts in 1892, when his Sedgwick Prize Essay was published. The Jurassic rocks of England were described systematically in the publications of the Survey, but much detailed work on the subdivisions of the strata by means of fossils has been done since the issue of the volumes dealing with the Jurassic rocks. A comprehensive account of these was published by Dr. W. J. Arkell, whose useful work (*The Jurassic System in Great Britain*, Oxford University Press 1933) has given a great impetus to the study of these strata. Similarly, considerable addition to our knowledge of the Gault and the Hunstanton Red Rock has been made by independent investigators since the appearance of the first volume of the Geological Survey's Memoirs on the Cretaceous Rocks. Some of the results of these investigations are included in the Monograph of the Gault Ammonites by Dr. L. F. Spath (published by the Palaeontographical Society), and in a series of shorter stratigraphical papers.

The Lower Greensand has attracted attention from early times, for the bed of fuller's earth at Woburn was first described in 1662. The phosphatic deposits of Potton and Wicken were discussed by J. J. H. Teall in 1875, and those of Upware and Brickhill in 1883 by Walter Keeping, both studies being subjects of the Sedgwick Prize Essay of the University of Cambridge. The fine sands in the Lower Greensand are of commercial value and have been studied from a modern point of view by Professor P. G. H. Boswell, his Memoir (published by the Imperial College of Science, 1918) being issued at a time when such material was in great demand. The mineral constitution of this formation and of the Hunstanton Red Rock was studied by R. H. Rastall (Geological Magazine 1919, 1925, 1930) and enabled him to draw important conclusions as to the source of origin of the constituents and the conditions of deposition. The history of the Lower Cretaceous Period in England has been studied by Dr. J. F. Kirkaldy (Geologists' Association, 1939), whose investigations have enabled him to present a clearer picture of the physical conditions than was formerly possible. Prof. L. Hawkes has recently examined the large collection of extraneous rocks from the Cambridge Greensand in the Sedgwick Museum; he has traced some to their source and explained the mode of transport (Geological Society 1943.)

The Chalk occupies a large part of the region, although its surface is mostly covered by later accumulations. Subdivision of this thick formation by means of fossils, first accomplished by Professor Charles Barrois, of Lille, was adapted by the Survey, whose scheme still holds good. More recently detailed studies on the unique exposure of Chalk at Trimingham were published by R. M. Brydone (Geological Society 1911), the Chalk of the Thetford district has been dealt with by Mr. H. Dixon Hewitt (Geologists' Association 1924), and that of the Cambridge district by Mr. A. G. Brighton (Geological Magazine 1928) and Mr. H. J. Osborne White (1932, Geology of Saffron Walden, *Mem. Geol. Surv.*). The interesting problem of the origin and constitution of the Chalk has recently been reviewed by Mr. Maurice Black, in a lecture to the Geological Society (April 1953).

Early Tertiary strata enter very little into the geology of the district. They were discussed in detail by Professor Boswell (Geological Society 1915), and among the results of significance in this region is the light they threw on the instability of the area during Tertiary times.

The Crag deposits of East Anglia, with their abundant and well-preserved shells and remains of other organisms, have formed the basis of a voluminous literature. In particular the Cromer Forest Bed is well known on account of the remains of trees and plants and the number of bones and teeth of large vertebrates that it has yielded. Among the early workers who started to make known the Crag deposits and their fossils were Edward Charlesworth, Lyell, and Searles Wood, while Owen, the anatomist, dealt with the vertebrata. In 1863 Ray Lankester began to publish on the vertebrate remains, and in the following year Huxley began his work on fresh finds. Later, Boyd Dawkins, Hugh Falconer, and E. T. Newton joined the band of workers on these interesting fossils.

Most of the groups of invertebrates are represented among the fossils of the Crag, and it is interesting to note that the first volume published by the Palaeontographical Society (1848) was a monograph on the univalved shells, by Searles Valentine Wood. Other groups of Crag fossils that have been described and figured in the monographs of that Society are the corals, cirripedes, echinoids, ostracoda, polyzoa, foraminifera, and elephants.

Names that will always be associated with the study of the Crag deposits are Searles Wood, Harmer, and Clement Reid. Searles Wood's son, of the same names as his father, also devoted himself to the study of the Crag. In 1864 he made the acquaintance of Frederick William Harmer, of Cringleford, Norwich, and for some years the two worked together. Both contributed papers to the Geological Society on the East Anglian Crags, and in his later years Harmer became the author of a monograph of the univalved shells (Palaeontographical Society 1914-1925). Clement Reid made a comprehensive study of the Pliocene deposits of this country and of comparable areas in western Europe. His memoir *The Pliocene Deposits of Britain* was published by the Geological Survey in 1890. In recent years, however, the position of the

Crag beds in classification has been under discussion, and a new scheme was recommended in 1952 by the International Geological Congress. Professor Boswell (Geologists' Association 1952) gave reasons for adopting the base of the Red Crag as the beginning of the Pleistocene in this country.

East Anglia is of special interest to the archaeologist because of the fundamental discoveries relating to the history of Early Man that have been made within the area. The first discovery of historic significance was made as long ago as 1797 in a brickyard at Hoxne, a village in the Waveney valley, in northern Suffolk. Here John Frere found shaped flints which he not only recognized as human implements, but he also conjectured, from the situation in which they were found, that they belonged " to a very remote period indeed, even beyond that of the present world ". For a long time the announcement of this discovery was forgotten, but in 1859 Hoxne brickyard was again the scene of archaeological investigations, for Prestwich and Evans had entered the field. In 1872 the latter published the first edition of his well-known *Ancient Stone Implements of Great Britain*. S. B. J. Skertchly, as a result of his survey of the Fenland, published in 1877, held the view that Man was a pre-glacial inhabitant of this country, but his opinion was not generally accepted. In more modern times an important stage in the history of investigations was reached in 1908 when the Prehistoric Society of East Anglia (now the Prehistoric Society) was founded by W. G. Clarke and W. A. Sturge. The publications of this Society contain a wealth of information concerning the occurrence of flint implements in East Anglia.

Meanwhile discoveries were being made which tended to prove that Man existed earlier in geological time than was supposed, for in 1905 W. G. Clarke found worked flints beneath the Norwich Crag. Little importance was attached to these finds until J. Reid Moir shortly afterwards found beneath the Red Crag shaped flints which he identified as the work of Early Man. Reid Moir continued his researches and added steadily to our knowledge of the subject. About the time of his early discoveries Lankester was also devoting some attention to humanly-worked flints, and as a result of Reid Moir's activities, was led to study those found beneath the Crag. Lankester's memoir, published by the Royal Society in 1912, attracted much attention, and was followed by a detailed description of the best example of a rostro-carinate implement then known (Royal Anthropological Institute 1914). This specimen, from the collection of W. G. Clarke, selected for description and argument as an example of human workmanship, is now the famous ' Norwich Test Specimen '.

By this time a band of investigators was busy in East Anglia, collecting, discussing, and publishing their results. Representative examples of their finds are in the museums at Ipswich, Norwich and Saffron Walden, each of which has consequently become a Mecca for investigators interested in the study of the subject. In this direction Reid Moir was the most substantial contributor to literature, and a comprehensive account of the subject is contained in his stimulating book *The Antiquity of Man in East Anglia* (Cambridge University Press 1927). Other investigators, whose work has added much to our knowledge, include Mr. A. Leslie Armstrong, Mr. M. C. Burkitt, Dr. Grahame Clarke, Mr. F. N. Haward, Miss Nina Layard, Dr. A. E. Peake, Mr. J. E. Sainty, Mr. A. C. Savin, and Dr. W. Allen Sturge, whose extensive collection formed the subject of a catalogue by Reginald A. Smith (British Museum 1931).

In addition to the importance of the area on account of the Crag deposits and the early human sites, East Anglia has within its borders the most complete succession of glacial deposits in this country. Nearly a century ago Lyell was attracted by the striking contortions in the cliffs on the northern coast of Norfolk, and noticed the similarity of these to features that he had seen in Denmark. About the same time James Mitchell observed that some of the erratics in the Drift must have been transported from Scandinavia. Many workers have studied the Superficial Deposits since then, among them Joshua Trimmer, Prestwich, and Searles Wood the younger. The last-named, in co-operation with F. W. Harmer, surveyed an area of 2,000 square miles in East Anglia, and their map of the Drift, on the scale of one inch to the mile, was claimed to be the first of its kind. Among the more modern works, mention should be made of papers by Professor Boswell on *The Stratigraphy of the Glacial Deposits of East Anglia in relation to Early Man* (Geologists' Association 1932) and *The Ice Age and Early Man in Britain* (Presidential Address, British Association 1932), and the paper by Dr. J. D. Solomon on *The Glacial Succession on the North Norfolk Coast* (Geologists' Association 1932). Investigation of the structure of the glacial deposits has been carried out for many years by Dr. George Slater, whose results have been made known in a series of publications. Recent excavations at Brundon, on the Suffolk-Essex border, have exposed glacial and interglacial beds with associated fossils and flint implements. The rich mammalian fauna was described by Dr. A. T. Hopwood, the non-marine shells by Mr. A. S. Kennard, erratics by Mr. D. F. W. Baden-Powell, foraminifera by Mr. C. D. Ovey, and archaeology by Reid Moir (Prehistoric Society 1939).

A study of the direction of ice-movement, as deduced from the matrix and pebble-content of the Chalky Boulder Clays, has enabled Mr. Baden-Powell (Geological Magazine 1948) to correlate them with boulder clays in other parts of the country. A comprehensive monograph of the Pleistocene Period (its Climate, Chronology and Faunal Successions) by Professor F. E. Zeuner, was published by the Ray Society in 1945.

Members of the Cambridge School, especially the late Professor J. E. Marr and Professor W. B. R. King, have done much to elucidate the history of the gravels of the Cam Valley and the lower part of the Great Ouse Basin (Geological Society 1920 and 1926), and Dr. T. T. Paterson has described a succession in the Breckland involving three glaciations with interglacial phases and associated flint implements.

The Fenland deposits, exceptional in many respects, were described in some detail by S. H. Miller and S. B. J. Skertchly in 1877 and 1878. Interest in these deposits has recently been revived, and the Fenland Research Committee, formed in 1932 for the purpose of co-ordinating the work of archaeologists, geologists, botanists and zoologists, has already produced most important results. One important contribution on the origin and stratigraphy of the Fenland deposits forms part of the studies of the Glacial History of British Vegetation, by Drs. H. Godwin and M. H. Clifford (Philosophical Transactions, Royal Society 1938, 1940). This was followed by work on the Norfolk Broads by Mr. J. N. Jennings and Dr. J. M. Lambert, the latter discussing a new view of their origin (Presidential Address, Norfolk and Norwich Naturalists' Society 1953).

Recent changes on the coast of this region are worthy of note, not only on account of their significance but also because they provide illustrations of geological processes actually in operation. Attention has been drawn to this branch of the subject by Professor J. A. Steers of the Department of Geography, Cambridge, who has made an intensive study of parts of the northern coast of Norfolk. A modern description of the coast of this area is included in his *Coastline of England and Wales* (Cambridge University Press 1946).

The underground structure of the region, which throws so much light on the disposition and thickness of strata, has been dealt with by Professor Boswell (Geological Society 1915) and by Dr. R. H. Rastall (Geological Magazine 1925), and, more recently, seismic methods of investigation have been employed by Messrs. E. C. Bullard, T. F. Gaskell, W. B. Harland and C. Kerr-Grant (Philosophical Transactions, Royal Society 1940). Exploratory work on underground structure has also been carried out for the Anglo-Iranian Oil Company, and an account of the results has been given by Dr. P. E. Kent (Geological Magazine 1947). Dr. A. W. Woodland has studied a large part of the area from the point of view of water-supply from underground sources, and the results of his collation of well-records have extended our knowledge of buried channels and have also shown that the outcrop of the Crag deposits is continued under cover south-westwards. The revised outcrop, based on Dr. Woodland's map (Geological Survey Wartime Pamphlet No. 20, 1946) is included in the Frontispiece and (in broken lines) in Fig. 14.

Only a few separately published works on the geology of the region have appeared. Of these the oldest is the interesting little volume by Samuel Woodward, an *Outline of the Geology of Norfolk* (1833), containing a coloured geological map and sections of the cliffs, and many illustrations of fossils from the Chalk and the Crag. The large volume on *The Fenland past and present* by S. H. Miller and S. B. J. Skertchly was published in 1878. Two more modern books which have been of great value to students are F. R. C. Reed's *Handbook of the Geology of Cambridgeshire* (Cambridge University Press 1897) and the *Handbook to the Natural History of Cambridgeshire* (Cambridge University Press 1904), with a chapter on the geology by Professor W. G. Fearnsides. The geology of Cambridgeshire, Bedfordshire and West Norfolk was dealt with by R. H. Rastall in *Geology in the Field* (Geologists' Association 1909), and in 1951 Mr. J. E. Sainty made the geology of Norfolk the subject of a Presidential Address (Norfolk and Norwich Naturalists' Society 1951).

A list of publications of the Geological Survey dealing with East Anglia and adjoining regions, most of which include full bibliographic references, is to be found on p. 98. These works, and those of other authors named, have been freely used in the preparation of this Handbook. Acknowledgment is also made to Mr. D. F. W. Baden-Powell, Professor P. G. H. Boswell, Mr. A. G. Brighton, Dr. K. P. Oakley, Mr. C. D. Ovey, Mr. J. E. Sainty, Dr. L. F. Spath, and Professor J. A. Steers, who have kindly supplied information on certain points.

The illustrations in this Handbook are mostly the work of Miss O. F. Tassart, some are by Mr. R. H. Lennie, and those of the Cambridge Greensand fossils by Mrs. H. Bowie.

The formations present in the area are set out in order below:

Superficial deposits

Recent and Pleistocene:	Shingle; Blown Sand Alluvium and Fen Deposits Clay-with-Flints; High-level Gravels Glacial and Interglacial Deposits

Solid formations

Pleistocene:	*Leda myalis* Bed Cromer Forest-bed Series Weybourne Crag Chillesford Beds Norwich Crag Red Crag
Pliocene:	Coralline Crag Nodule Bed
Eocene:	London Clay Reading Beds Thanet Beds
Cretaceous:	Chalk Cambridge Greensand Gault; Hunstanton Red Rock Lower Greensand; Neocomian Beds
Jurassic:	Kimmeridge Clay Corallian Beds Oxford Clay and Kellaways Beds Cornbrash Blisworth Clay Great Oolite Limestone Upper Estuarine Series

II. JURASSIC STRATA

Introduction

THE OLDEST STRATA that appear at the surface in this area belong to the Jurassic System, a series of clays and limestones that received its name because of its extensive development in the Jura Mountains, in France and Switzerland. These Jurassic strata, which form part of a great belt that runs across England from Dorset to Yorkshire, crop out in the western part of our area. They are inclined at a very low angle towards the south-east and so pass under newer strata in that direction. In their general arrangement therefore, if the outcrops were always visible, we should see, in successive order, only the eroded edges of these formations. On account of the inclination of the strata the older members of the Jurassic System crop out to the west of the area, but we are concerned only with parts of the Middle and Upper divisions.

The first deposits to be described belong to the Great Oolite Series, a variable group of strata named after the most characteristic member, a massive oolitic limestone, which is more fully developed in other parts of the country.

Fossils are commonly found in these strata, and show that the deposits were formed under different conditions, mostly marine, but in places estuarine; while remains of giant amphibious dinosaurs (*Cetiosaurus*) indicate that land, especially in the Midlands, was at times not far distant. From a study of the present distribution of the Great Oolite and of the position of the older rock-masses it is possible to reconstruct the main outlines of the geography of the time when the strata were being deposited. Most of the area of Great Britain then lay between two continental land-masses. On the west stood the ancient 'North Atlantis' including all of what is now Ireland (excepting the north-eastern portion), most of Wales, Cornwall and parts of Devon. This land extended westwards, northwards past Iceland, and southwards, including what is now Brittany. On the east stood what was virtually an extension of the present Scandinavia, covering most of the area of the North Sea and running roughly parallel to and some distance from our present eastern shores, with its southern limit turning eastwards north of Norfolk so as to run approximately along and just within the present northern coastal area of Germany.

A sea lay within these two land-areas forming a strait to the north between the two land masses, but broadening out south-eastwards and extending over France and Germany. Two great islands stood out in this sea: one on the north covered most of Scotland and extended southwards over the Pennines, while on the south one stood approximately on the site of East Anglia and Essex and continued south-eastwards over the Ardennes. The sea extended over the area of the present English Channel, skirted Cornwall and part of Devon, stretched as a narrow arm over the Bristol Channel, passed along the eastern and northern borders of Wales, across north-east Ireland and thence northwards to join the northern straits. Narrow straits separated the two great islands from the eastern land-mass.

Such were the broad outlines of the distribution of land and sea at the time when we begin the history of our area. Rivers, wasting the land, carried their burden of sediments into the sea and spread it over its floor; and after chemical and physical changes these became stratified rocks. But changes in the relative position of land and sea, rising and falling of the sea-floor along certain lines, and the comings and goings of animals and plants were always in progress; and so the story is one of successive series of deposits, nearly all containing the embedded remains of the life of the time.

Middle Jurassic Strata

Of this division only the Upper Estuarine Series, the Great Oolite, and the Cornbrash come to the surface in this region; they occupy only small areas on its western borders (Pl. I). One area is an irregular winding tract in the valley of the Great Ouse, west and north-west of Bedford, and the other extends north-westwards from near Podington.

THE UPPER ESTUARINE SERIES

This formation consists of variegated sandy clay with occasional layers of limestone, deposited under alternate marine and freshwater conditions. In thickness it varies from 15 to 30 ft. Fossils are scarce, but marine shells (*Pholadomya*, *Modiolus*, *Ostrea*, etc.), freshwater shells (ffl*nio* and *Cyrena*), and plant-remains have been found. Shallow sinkings have shown that it overlies the Northampton Sands (Inferior Oolite) and the Upper Lias; and at Bedford it occurs 70 ft. below the surface. Beds of this series come to the surface near Harrold, and at Sharnbrook, north-west of Bedford. The Upper Estuarine Series has been correlated with the Hampen Marly Beds, part of the Great Oolite Limestones in Oxfordshire.

After the deposition of the Upper Estuarine Series the conditions in our area gradually changed, and definitely marine conditions were established. As a result deposits that are now limestone, marl or clay, were laid down—these are referred to two divisions of the Great Oolite Series, the Great Oolite Limestone and the Blisworth Clay.

THE GREAT OOLITE LIMESTONE

Cropping out in the same narrow tract that extends from the south of Bedford north-westwards are beds of grey and bluish limestone, separated by thin beds of clay or marl, the whole attaining a maximum thickness of about 30 ft. The limestone-beds vary in thickness from 1 to 10 ft. and show signs of current-bedding; they have been used for lime-burning and building-stone near Bedford. Shells are found commonly in these beds, and include the oysters *Ostrea hebridica* (=*sowerbyi*) and *Ostrea subrugulosa*, and other bilvalved sheels such as *Modiolus imbricatus*, univalved shells (*Natica* and *Nerinea*), shells of brachiopods (*Ornithella* and *Kallirhynchia concinna*), echinoids, and corals; remains of saurians (*Cetiosaurus*) have also been found.

The term ' oolite ' (Greek, *oon*, an egg) has reference to the nature of the rocks, which in some parts of the country consist to a large extent of minute spheroidal grains somewhat resembling the roe of a fish. This division of the Great Oolite Limestone is sometimes known as the White Limestone, a name that is perhaps more appropriate in this area, since the beds are rarely oolitic here.

THE BLISWORTH CLAY

Resting impersistently on the limestone is the Blisworth Clay, only a few feet in thickness. This clay, sometimes referred to as the Great Oolite Clay, is variable in colour, and in places is calcareous; a nodular ironstone band occurs near the base. The fossils are similar to those of the White Limestone, and the two species of oysters are again found in profusion.

THE CORNBRASH

As represented in other parts of the country, the Great Oolite Series is a complex formation, laid down under varying conditions. In our area, its representation by the strata that have been briefly described, is simple. But after the last of the varied deposits of the series had been laid down, a more widespread change of marine conditions took place and resulted in a general extension and transgression of the sea. The deposits of this sea formed what is known as the Cornbrash, a formation that extends with little interruption from Dorset to Yorkshire.

Although this formation is so constant throughout the country its outcrop is nowhere very wide, and within the area under description it is narrow because of the reduced thickness, the beds being rarely more than 3 ft. The outcrop forms a thin border to that of the Great Oolite Series in the Ouse Valley, previously mentioned. The only other occurrence in the area is a small tract (a faulted inlier) between Stilton and Yaxley, south of Peterborough, but the exposure is now obscured.

On account of the thinness of the formation the interesting features observable in other parts of the country are not so apparent. Elsewhere there is evidence that the conditions established by the general marine transgression did not remain settled for long, and that a renewal of transgressive movement took place. As a result two divisions of this formation are recognizable, the Lower and the Upper Cornbrash. These differ in lithology as well as in the fossils that they contain. In places marking the line of junction and the plane of the second transgression is a pebble-bed.

In the Ouse valley, although the Cornbrash is very thin, both divisions are present. Fossils recorded from Yaxley show that both divisions were also exposed there. A typical section formerly exposed in a brickyard at Bourne End, Bletsoe, north-east of Sharnbrook, showed the formation to consist of a tough brown limestone (1 ft. 3 in.) overlain by sandy and calcareous fissile layers (1 ft. 6 in.).

Two kinds of ammonites are characteristic among the fossils of the Cornbrash; the thin, laterally-compressed *Clydoniceras* is found in the Lower division, and the robust, inflated, and plainly-ribbed *Macrocephalites* is restricted to the Upper division. Further means of subdivision are provided by the brachiopods: four zones, two lower and two upper, can as a rule be identified by means of these shells. Among the species of brachiopods are *Cererithyris intermedia*, *Ornithella obovata*, *Kallirhynchia yaxleyensis*, *Microthyridina siddingtonensis*, *M. lagenalis*, and *Rhynchonelloidella cerealis*. Dr. Arkell notes that the first-named, characteristic of the lowest zone, has not yet been recorded from the exposures near Bedford. A typical and common fossil of the Lower Cornbrash is the small shell *Meleagrinella* [*Pseudomonotis*] *echinata*; the sharply-folded oyster-shell *Ostrea* (*Lopha*) *marshii* characterizes the Upper Cornbrash.

The Cornbrash received its name because of its giving rise to a stony or brashy soil, favourable to the growth of corn. At one time it was known locally as the Bedford Limestone and was quarried for building-stone and used also for lime-burning.

UPPER JURASSIC STRATA

KELLAWAYS BEDS AND OXFORD CLAY

The thinness of the Cornbrash was doubtless due to a local uplift of the sea-bed at the time of deposition, a point to be referred to later (p. 19). A downward movement ensued, for a deposit of clay overlies the Cornbrash and indicates much deeper water. This condition did not remain settled for long, and another slight uplift caused the deposition of 10 or more feet of sandy material, after which the area gradually sank and a deposit of more than 500 ft. of muddy material (now mostly clay) accumulated.

The clay and sandy beds immediately above the Cornbrash are known as the Kellaways Beds, being named after the village of Kellaways, in Wiltshire, where similar beds were formed. The thick clay above is the Oxford Clay, the formation being continuous with that under the city of Oxford.

The Kellaways Clay is mostly of a bluish colour, and in the neighbourhood of Bedford it attains a thickness of 10 feet. In this area also the sandy beds above the clay are well developed, and in parts the sand is consolidated into irregular concretionary masses (' doggers '), some as much as 10 ft. across. Fossils are not common in the clay, but in the sandy beds above (sometimes called the Kellaways Rock) shells are frequently found, among them the bivalves *Pleuromya alduini* [=*recurva*], *Oxytoma expansa* and the oyster-like *Gryphaea bilobata*. The ammonite *Sigaloceras calloviense* is found here, and lignite is also included.

The Oxford Clay is not homogeneous throughout; at various levels the segregation of limy material gave rise to bands of limestone varying in thickness from a few inches to several feet, and some beds include a proportion of sand. Concretionary nodules of calcareous stone and of iron sulphide (pyrites) and water-clear crystals of selenite (sulphate of lime) are also of frequent occurrence. In colour the main mass of the clay is greenish or bluish-grey, becoming brown on weathering, and in consistency it is tenacious, but is shaly and laminated in places.

Fossils are abundant throughout the formation, and nearly all classes of animals are represented. They include several kinds of saurians and numerous species of ammonites, lamellibranchs, gastropods, brachiopods, and crustacea. The large inflated oyster *Gryphaea dilatata* is particularly common, and the mussel *Modiolus bipartitus* is frequently found. Clustered tubes of the marine annelid *Serpula vertebralis* and the stout guards of the belemnite *Cylindroteuthis oweni* are typical. Most of the species of fossils have a long range in the formation, but the ammonites are limited in their vertical ranges and may therefore be taken as reliable guides to their respective horizons in the formation, since the various species occur in regular sequence. Thus it is possible to determine subdivisions in the Oxford Clay by means of the occurrence of ammonite-species; accordingly certain thicknesses of beds within the formation have been termed ' zones ' and named after a species of ammonite found therein. Such a means of subdivision is necessary in a thick formation that shows but little variation in lithology. Also, in the case of a formation becoming thin it provides a means of telling whether such thinning is due to paucity of sedimentation caused by the rising of a submarine ridge, or to subsequent erosion (in which case particular zones would be absent).

The ammonite species of the Oxford Clay after which zones have been named, are as follows, in order of occurrence, beginning with the lowest: *Kosmoceras jason*, *Erymnoceras coronatum*, *Peltoceras athleta*, *Quenstedtoceras lamberti*, and *Cardioceras cordatum*.

In our area the Oxford Clay occupies a large extent of flat country in Bedfordshire and stretches over the greater part of Huntingdonshire and into Cambridgeshire. It underlies a considerable part of the Fenland (on the west) and comes to the surface at the ' islands ' of Ramsey, Whittlesey, and Thorney. It extends beyond the margins of the area on the west, while the easterly limit of its outcrop in the area is difficult to determine because of a covering of Drift (see p. 58) and because the succeeding formation is a clay similar in lithic character. Brickyards have been opened in the Oxford Clay in various parts of the area, particularly in the neighbourhood of Peterborough. The Oxford Clay of this locality is famous for the large number of remains of reptiles that have been found. The various groups (dinosaurs, crocodiles, pliosaurs, ichthyosaurs and plesiosaurs) represent forms from the land, from swampy ground, from near shores, and from the open sea.

Detailed study of the Oxford Clay around Woburn Sands, Ampthill, and Sandy, by means of the ammonites, shows that the highest beds were eroded before the succeeding formation was laid down.

CORALLIAN BEDS

The formation that normally overlies the Oxford Clay has been called the Corallian because of the abundance of corals in it in some parts of the country. In our area coralline rock occurs in only one mass, at Upware, 10 miles north-east of Cambridge, and the Corallian formation is represented otherwise by clay, with a basal rock-bed.

Erosion of the highest beds of Oxford Clay around Ampthill has already been referred to; these highest beds have similarly been eroded at Upware. Evidently at the end of Oxford Clay times a local uplift of the sea-bed took place; this can be traced by a gradual easterly overstep of the upper zones of the Oxford Clay by the base of the Corallian formation, which is represented in various places by the Oakley Beds, the Elsworth Rock and the St. Ives Rock.

Oakley Beds; Elsworth Rock; St. Ives Rock

The Oakley Beds have been traced into our area from the south-west, where they are typically developed. They comprise variable beds (6 to 10 ft.) of clay, limestone, and marl, characterized by the presence of brown ooliths. The abundance of small oysters (*Exogyra nana*) and of clustered tubes of the marine annelid *Serpula* is typical; and the age of the beds is determined by the presence of certain ammonites (Perisphinctids), usually fragmentary.

A section in the railway-cutting at Ampthill (Bedfordshire), now overgrown, showed the upper beds of Oxford Clay succeeded by Corallian beds (61 ft.), and then a small thickness of the next formation, the Kimmeridge

A. SCENERY OF SANDRINGHAM SANDS COUNTRY, SANDRINGHAM—KING'S LYNN CROSSROADS, NORFOLK.

B. SAND-PIT IN LOWER GREENSAND, NEAR LEIGHTON BUZZARD.

(*For full explanation, see p. v.*)

A. FLAT TOPPED ESKER AT HILDERSHAM, CAMBRIDGESHIRE.

B. TERTIARY BEDS ON CHALK. BRAMFORD, SUFFOLK.

(*For full explanation, see p. v.*)

Clay. Here the base of the Corallian is a rubbly rock-bed (4 ft. 6 in.), with *Exogyra nana* and other shells; this is the representative of the Oakley Beds. These beds are also represented at Sandy, to the north-east of Ampthill; while at Gamlingay, a few miles east of Sandy, just within the borders of Cambridgeshire, the basal rock-bed is again similar to that at Ampthill.

In Cambridgeshire and Huntingdonshire the basement-bed is known as the Elsworth Rock, and its thickness varies from 10 to 15 feet. Here the bed is in two bands, separated usually by 5 ft. of clay, the rock-bands consisting of grey shelly limestone full of brown ooliths, as are the Oakley Beds. Fossils, mostly bivalved shells, are particularly common in the Elsworth Rock, and include *Trigonia hudlestoni*, *Astarte ovata*, *Chlamys fibrosa*, *Exogyra nana*, and *Oxytoma expansa*. Among the ammonites of this rock are certain species of *Perisphinctes* and *Cardioceras* which normally do not occur together. From the evidence of the ammonites and the condition of some of the specimens (which show that the shell was removed and worm-tubes became affixed to the internal cast beneath) it is concluded that erosion was in progress while the bed was being formed, and that sedimentation was in consequence slow and scanty, so that the shells of later arrivals became mixed with those of the earlier assemblage.

It is to be noted that, although the Elsworth Rock and its equivalents form the base of the Corallian in this area, an earlier deposit of Corallian age (the Lower Calcareous Grit) is present in other parts of the country.

In the neighbourhood of St. Ives, in Huntingdonshire, the base of the Corallian is marked by the St. Ives Rock, a development similar to the Elsworth Rock. The fossils of this bed are also similar, but the echinoids are a more conspicuous element, the commonest species being *Collyrites bicordata*. The St. Ives Rock is to be regarded as a local variant of the Elsworth Rock.

Ampthill Clay

Above the rock-bed at the base of the Corallian is a thickness of clay with subordinate thin bands of limestone in the lower part. This clay formation takes its name from Ampthill, in Bedfordshire, but has also been referred to as the Bluntisham Clay, the Tetworth Clay, and the Gamlingay Clay.

Near the middle of the Ampthill Clay is a variable band of limestone in two nodular layers, separated in places by a clay-parting. This limestone, which is from 2 to 3 ft. in thickness, is hard, compact, grey in colour, and highly fossiliferous, is known as the Boxworth Rock. Among the fossils found in it, besides sundry ammonites, are the bivalved shells *Trigonia clavellata* and *Nucula menkii*, and the univalved shell *Alaria bispinosa*. By means of its fossils this rock is correlated with the *Trigonia clavellata* Beds of Dorset. The Ampthill Clay is thus equivalent to the upper part of the Corallian formation.

The main mass of the Ampthill Clay is very dark, and in places almost black; and large crystals of selenite are abundant. Among the fossils the large oyster-like *Gryphaea dilatata* var. *discoidea* is common; *Thracia depressa* is also typical. Ammonites include *Amoeboceras* (*Prionodoceras*) *serratum*, and the large belemnite *Pachyteuthis excentrica* is frequently found. A notable

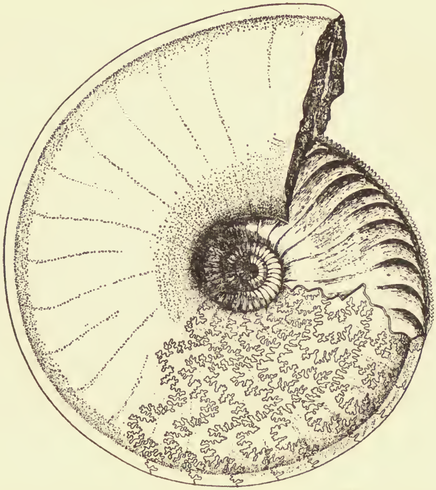

FIG. 1. *Ammonite from the Ampthill Clay*—Amoeboceras (Prionodoceras) serratum (*J. Sowerby*) × ⅔.

feature of the large shells of the Ampthill Clay is that they are generally encrusted with worm-tubes, and the fossils of this formation are rarely pyritized as are those of the Oxford Clay.

The Upware Coral-rock

One of the most interesting features of the Corallian formation is the abrupt change in its lithic character in the neighbourhood of Oxford. Around that city, and along the outcrop of the formation to the south-west, the beds are of shallow and sometimes clear-water origin; they are mostly limestones and show evidence of abundant coral-life. Near Wheatley, 5 miles east of Oxford, the limestone development ends abruptly, and the formation continues from there north-eastwards to Yorkshire in a clay-facies, with only one isolated limestone patch intervening. This patch is a small area of coral-rag and oolite, 3 miles in length and nearly a mile wide, which rises above the fen-level at Upware, 10 miles north-east of Cambridge (Fig. 2).

Resting on an eroded surface of the Oxford Clay here is a 4-ft. band like the Elsworth Rock, but containing ammonites which suggest that it may have been formed rather earlier. Above the rock-band is a thickness of variable rock, a mixture of coral and marl (5 ft. or more) and then a hard band of coral rag. Succeeding the coral rag is a mass of shelly oolite (20 to 40 ft.) with abundant fossils. Among these are the bivalved shells *Chlamys nattheimensis*,

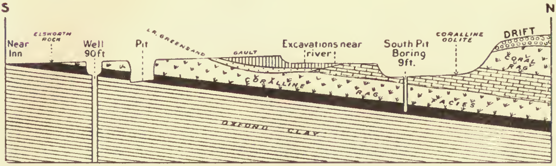

FIG. 2. *Diagrammatic section through the Corallian Beds on the south side of the hill at Upware, Cambridgeshire.*

(After P. Rigby *in* R. H. Rastall 'Geology in the Field', p. 137, Fig. 26, *Geol. Assoc.* 1909; and W. J. Arkell, '*The Jurassic Rocks of Britain*', 1933, p. 415, Fig. 73.)

Mytilus ungulatus, Velata anglica and *Myoconcha texta*. Commonest among the echinoids are *Nucleolites scutatus, Holectypus depressus* and *Hemicidaris intermedia*. Perisphinctid ammonites are also found.

The top bed is a coral rag, composed of creamy limestone made up of reef-building corals with pockets of earthy rock containing remains of shells. The chief corals are *Thamnasteria arachnoides, Stylina tubulifera* and *Isastraea explanata*. Most of the bivalved shells in this bed occur also in the oolite below, with the addition of certain species of *Isoarca* and *Opis* which are almost peculiar to it in this country.

This occurrence of coral-rock has been regarded as an isolated reef, but recent investigation has shown that the rock-mass has a considerable lateral extent and that the present outcrop is the result of pre-Cretaceous folding trending N.N.E.-S.S.W. Borings have proved that, beyond the outcrop, beds of a similar type extend beneath Lower Cretaceous beds and Drift deposits. The coral-rock forms the core of a domed structure, of which the upper part is Ampthill Clay in conformable sequence.

THE KIMMERIDGE CLAY

Deposition of muddy sediments continued after the accumulation of those that formed the Ampthill Clay, and produced the material now known as the Kimmeridge Clay, a thick formation that extends across England from Dorset to the south-western border of our area. In East Anglia the outcrop of the Kimmeridge Clay is discontinuous. In Bedfordshire it does not appear, having been eroded before the lowest Cretaceous strata (the Lower Greensand) were deposited (see p. 19), but it emerges from beneath the cover of Lower Greensand at Great Gransden, 10 miles west of Cambridge, and extends from there towards the Wash, underlying the eastern part of the Fens. The outcrop, narrow until it reaches a point north of Cambridge, widens out under the eastern part of the Fenland, and forms part of the straggling 'islands' on which Southery, Chatteris, Littleport, and Ely stand. In western Norfolk the formation extends as a narrow border to the Lower Greensand from Hilgay to just north of King's Lynn. It is exposed in the Roslyn Pit, Ely, and at Haddenham, Downham Market and Watlington (Norfolk), and has been used for the making of bricks and tiles, but the highest beds are too bituminous for this purpose.

FIG. 3. *Fossils from the Jurassic strata.*

Although the conditions of deposition of the Kimmeridge Clay and the Ampthill Clay were much the same, there was some interruption after the Ampthill Clay was deposited because the base of the Kimmeridge Clay is marked by a layer of phosphatic nodules, as at Haddenham.

The Kimmeridge Clay is of a dark bluish-grey colour, and is shaly in parts; thin layers of cement-stone are occasionally developed. Fossils are found throughout the formation, and some are common at certain horizons. Thus the lowest beds are characterized by the frequency of large flat oyster-shells, *Ostrea delta*, while the small incurved radially-ribbed oyster *Exogyra virgula* has a longer range in the lower part of the formation. At a lower horizon in the clay near Ely, large aptychi (*Laevaptychus flamandi*) are very common; these are the covering plates of the apertures of ammonites. Near the same horizon also are bituminous shales with shells of the discoid brachiopod *Discina latissima*. The small bivalved shell *Lucina minuscula* occurs in abundance in the upper beds.

Remains of fish (*Asteracanthus*, *Gyrodus*, *Hybodus*, &c.) and of marine reptiles (*Cimoliosaurus*, *Dacosaurus*, *Ichthyosaurus*, &c.) have been found at various horizons.

Ammonites occur almost throughout the formation, mostly in a crushed condition, and their restricted vertical range and constant order of occurrence have provided a means of subdivision into zones. These zones enable us to compare the formation in our area with its developments in other parts of the country. Thus, although the Kimmeridge Clay is thin here (125 ft.) while in Dorset it is substantially thicker (more than 1,500 ft.), the distribution of the ammonites shows that this thinness is not due entirely to subsequent erosion, although the uppermost zones have been removed. Most of the zones present in Dorset may be present in our area, but their attenuation is due to a slower rate of deposition than occurred over the south of England. The thinning is gradual throughout the formation, each zone being reduced in individual thickness as traced from Dorset to Norfolk.

The interesting feature of gradual thinning has been proved to a large extent by boreholes drilled at Southery in exploration for oil-shale. One example of thinning is shown by the range of the pyritized radial plates of the free-swimming crinoid *Saccocoma*. These are restricted to a 1-ft. band associated with greenish-black oil-shale; in Dorset this crinoid has a vertical range of 13 feet.

The highest horizon of Kimmeridge Clay in our area is that characterized by the ammonite *Pavlovia rotunda*; its equivalent is seen in the well-known *Rotunda* Nodules at Chapman's Pool, Kimmeridge Bay, Dorset.

FIG. 3. *Fossils from the Jurassic strata.*

1. *Discina latissima* (J. Sowerby); 2. *Lucina minuscula* Blake; 3. *Ostrea delta* William Smith (x½); 4. *Isoarca texata* Quenstedt; 5. *Saccocoma sp.*, a pyritized radial plate (x4); 6. *Exogyra virgula* (Defrance); 7a, b. *Exogyra nana* (J. Sowerby); 8. *Oxytoma expansa* (Phillips) (x¾); 9. *Thamnasteria arachnoides* (Parkinson); 10. *Astarte ovata* William Smith; 11. *Alaria bispinosa* (Phillips); 12. *Collyrites bicordata* Leske; 13. *Opis virdunensis* (Buvignier); 14. *Modiolus bipartitus* J. Sowerby; 15. *Quenstedtoceras lamberti* (J. Sowerby); 16. *Kosmoceras duncani* Auctorum.

Along its outcrop to the south-west of our area the Kimmeridge Clay is succeeded by strata of Portland age, which in turn are usually overlain by beds of the Purbeck formation (mostly of freshwater origin), the last to be laid down during the Jurassic Period. Towards the end of the Jurassic Period the land had been steadily rising, and at the end of the Period the great land-mass on the west (Atlantis) and the great eastern (London-Ardennes) island became joined by a land-bridge that stretched across the Midlands. To the south of this was an extensive lacustrine area that covered the south-east of England as far west as Dorset, and extended still further southwards and eastwards: in this area the Wealden beds were deposited. To the north, covering what is now Lincolnshire, Yorkshire and North Norfolk, was an arm of the sea, on the floor of which marine Lower Cretaceous strata were formed.

No strata of Portland, Purbeck, or Wealden age are found in the area, and it is doubtful whether they were deposited further north than Bedfordshire. Fossils derived from Upper Jurassic beds have been found in Lower Cretaceous beds (Lower Greensand), as at Potton (Bedfordshire) and Upware (Cambridgeshire). At Potton remains of the dinosaur *Iguanodon* and the plant *Tempskyia*, both derived from Wealden beds, have been commonly found. As pointed out by Dr. Arkell, it is likely that, at the end of the Kimmeridge period the whole of northern Britain received an upward tilt which brought sedimentation to a standstill. For some time the area remained as land until submerged beneath the waters of the Cretaceous sea.

III. CRETACEOUS STRATA

NEOCOMIAN BEDS; LOWER GREENSAND

THE UPLIFT THAT brought the area above the level of the sea towards the close of the Jurassic Period was followed by gradual sinking. A long interval elapsed before this process set in, however, and considerable geographical changes took place. During this interval denudation was in progress on the land and was continued by active erosion by the sea that advanced during early Cretaceous times. Evidence of this erosion is provided by the fact that in places the lowest Cretaceous deposits contain fossils washed out during the destruction of Upper Jurassic strata.

Meanwhile the latest Jurassic formation that we know to have been laid down over the area was the Kimmeridge Clay, but the lowest Cretaceous beds do not rest everywhere on that clay. In places they rest on lower beds, the Ampthill Clay or the Oxford Clay. If we trace the lowest beds of the Cretaceous System north-eastwards from the south of Bedfordshire we find them resting on the Kimmeridge Clay near Leighton Buzzard, the Ampthill Clay at Ampthill, the Oxford Clay at Sandy, the Ampthill Clay at Gamlingay, and the Kimmeridge Clay again in north-east Cambridgeshire. Dr. Rastall has drawn attention to a denuded arch of Jurassic strata related to an axis, known as the Charnwood Axis, which can be traced south-eastwards from Charnwood in Leicestershire. He thought that this arch has repeatedly risen and subsided (one instance of its rising having been noted in the local thinning of the Cornbrash near Bedford) and that it had a dominating influence on the distribution of the Lower Greensand.

Dr. Rastall has also brought forward evidence of a second arch running parallel to it on the south-west, and extending in a line from Nuneaton past Leighton Buzzard: this has been called the Nuneaton Axis. From a study of the mineralogical character of the Lower Greensand between Leighton Buzzard and Hunstanton, he suggests that the Lower Greensand material was deposited in two basins, from the south-west and north-east respectively, these basins being separated by a land ridge along the line of the Charnwood Axis.

The oldest beds of Lower Greensand in our area occur in West Norfolk, where the formation comes to the surface in the rising ground on the eastern borders of the Fens, and can be traced, with a north to south strike, from Downham Market to Hunstanton.

It should here be remarked that the term Lower Greensand has been loosely applied to beds in Norfolk. Of the three divisions mentioned below only the Carstone is equivalent to the Lower Greensand of the South of England; the two lower divisions belong to an earlier stage—the Neocomian. As an indication of lithic character the term Lower Greensand applies more appropriately to beds in the south of England, but even there a green tinge (due originally to the colour of the grains of the mineral glauconite) is unusual; as a rule the beds are brown or yellow in colour, through oxidation. In our area the sandy beds are often nearly white (Pl. II B), and beds of clay, loam, and grit are also included.

In West Norfolk the following divisions can be recognized:

	Ft.
Carstone (a brown ferruginous sandstone)	40
Snettisham Clay (clays and loams)	30
Sandringham Sands (light silvery sands, with occasional stone bands) ...	100

The Sandringham Sands rest on an eroded surface of the Kimmeridge Clay and are mostly current-bedded, light-coloured, sharp and silvery, but in the upper part they are often stained and in places cemented into a flaggy brown stone, with obscure casts of shells. Wood and fragments of plant-remains are contained in pyritous nodules and in clayey streaks in the sand. Dr. Kirkaldy mentions the occurrence of unrecognizable ammonites in the phosphatic basal beds. The general aspect of the sands, with the exception of the lowest portion and probably the highest beds, is suggestive of estuarine conditions. The sands have been worked for glass-making near King's Lynn.

The Snettisham Clay has been traced as a continuous outcrop from Hunstanton, where it appears from beneath the Carstone, to south of Appleton, but it is partly hidden by superficial deposits at Heacham. Several species of fossils have been found in clay-ironstone nodules in this clay; they include the bivalved shells *Cardium*, *Panopea* and *Nuculana scapha* and the ammonoid shell *Paracrioceras occultum.* The occurrence of this ammonoid shows that the Snettisham Clay was deposited earlier than any Lower Greensand beds in the south of England. The clay thins southwards, where it becomes silty and changes into thin-bedded flaggy ferruginous sandstone with plant-remains. The Snettisham Clay has been worked for brickmaking at Snettisham, Dersingham and Heacham.

The Carstone division includes sands and ferruginous sandstone, the latter having been used considerably for building in the neighbourhood. At Hunstanton it is a brown pebbly sandstone, seen beneath the Red Rock and on the foreshore, where its quadrangular jointing is conspicuous. At the base of the Carstone at Hunstanton are concretionary and phosphatic nodules which yield fossils. These fossils include several species of ammonites, normally occurring at more than one horizon; the deposit here is evidently condensed. Among the forms are *Deshayesites fissicostatus* and other species of *Deshayesites*, *Dufrenoyia furcata*, *Ancyloceras*, *Cheloniceras*, and *Tropaeum. Isognomon* [*Perna*] *mulleti* has also been recorded. The first-named ammonite has not been found in the south of England, but some of the other forms are familiar in Kent and the Isle of Wight. Evidently about this time a southern sea had gained access to the south of England and shortly spread across the midland land-ridge and linked up with the sea on the north.

In the southern part of the Fens the Lower Greensand is thin (10 to 12 ft.); it caps ' islands ' at Ely, Borway, and Upware, and occupies stretches at Wilburton and Stretham. At Cottenham begins the outcrop which, with increasing thickness of the formation, extends almost continuously to the south-west corner of our area, at Leighton Buzzard. The Lower Greensand between Cottenham and Leighton Buzzard is probably of the same age as the Folkestone Beds in the south of England. Over a large part of the area, however, fossils are absent because of the permeability of the beds; and without short-ranged fossils such as ammonites exact correlation is impossible.

At Upware the Lower Greensand (12 ft.) is interesting on account of the presence of fossils derived from the destruction of Jurassic clays, as well as fossils of the period. Most of the derived fossils are from the Kimmeridge Clay and include bones and teeth of marine reptiles (*Pliosaurus*, &c.), fish (*Asteracanthus*, *Acrodus*, &c.), ammonites, and shells (*Protocardia*, &c.). Fossils from the Oxford Clay, Coral Rag, Portland beds and early Cretaceous beds also occur. The indigenous species are of several groups—fish, ammonites, univalved shells (*Littorina upwarensis*, *Pleurotomaria renevieri*, &c.), bivalved shells (*Plicatula carteroni* and *Pecten* (*Neithea*) *atavus*, *Opis neocomiensis*, &c.), polyzoa (*Ceriopora nodosa*, &c.), annelids, echinoids (*Hyposalenia wrighti*, &c.) and sponges (*Raphidonema macropora*, &c.). Brachiopod shells are especially common, and include *Zeilleria woodwardi*, *Rhynchonella upwarensis*, *R. antidichotoma*, *Terebratella davidsoni*, *T. fittoni* and *T. menardi*, and several species of *Terebratula* (*T. praelonga*, &c.). Among the fossils derived from early Cretaceous beds are *Terebratula rex*, *Cucullaea* (*Dicranodonta*) *donningtonensis*, and *Thetironia minor*. A similar association of derived and indigenous fossils is found at Potton, in Bedfordshire.

In southern Cambridgeshire the formation attains a thickness of 70 ft. and consists of brown and yellow sands, current-bedded and containing ironstone concretions. In Bedfordshire it consists mostly of ironsands with a thin bed of derived fossils and stones near the base. Near Woburn the unfossiliferous incoherent Woburn Sands are nearly 220 ft. in thickness and contain a band of fuller's earth just below the middle. At Leighton Buzzard it consists for the most part of silver sand, particularly suitable for filter-beds and glass-making.

Among the derived nodules and pebbles that were scoured out of older formations and included in the Lower Greensand, the phosphatic nodules (commercially called 'coprolites') are of especial interest. They have been found at Potton, Upware, Wicken, and other places, and their condition is due to the replacement of the original matter by phosphate of lime, probably during a long exposure on the sea-floor. The pebble beds of the Lower Greensand also include fragments of older rocks, among them vein-quartz, chert, quartzite, lydian stone and fragments of Palaeozoic grit and slate.

On account of its permeability the Lower Greensand is an important water-bearing stratum, and wells are sunk into it in many places. At the surface, in the parts where it is not covered by Drift deposits, it forms a conspicuous feature in the landscape.

The Lower Greensand was deposited in fairly shallow waters, but at the end of the period of its deposition an extensive subsidence brought about a complete change of sedimentation, and over most of our area a clay formation—the Gault—was deposited.

GAULT

Usually the Gault is a stiff tenacious clay of a dark grey colour; but in this area it shows changes in lithology as well as thickness. In Bedfordshire and Cambridgeshire the outcrop of this formation (obscured in places by a covering of Drift) runs as a narrow strip of clay land along the eastern margin of the Lower Greensand, from near Leighton Buzzard past Cambridge (where it widens out) to beyond Waterbeach, 5 miles north of Cambridge. Near

FIG. 4. *Fossils from the Neocomian beds and the Lower Greensand.*

here it disappears beneath the alluvium of the Fenland, but reappears as a limited patch round Wicken and Soham. Its outcrop north of this patch is obscured for some distance by Fen deposits, but it again appears on the eastern margin of the Lower Greensand near Stoke Ferry and extends as a narrow band northwards as far as Congham.

The fullest thickness of the Gault is at Totternhoe (Bedfordshire), where it is a dark grey clay about 230 ft. in thickness; it becomes thinner both eastwards and northwards, being 150 ft. at Cambridge and 90 ft. at Soham. In Norfolk its lithic character changes. At West Dereham it is a marly clay (60 ft.); north of this it becomes thinner, being 40 ft. at Shouldham; at Grimston (20 ft.) it includes beds of grey limestone and red marl. Further north, at Dersingham (7 ft.) it is a brown and red marly clay passing up into soft greenish-white marl, while between there and Heacham it changes into a red rock (known as the Red Chalk or, more correctly, the Hunstanton Red Rock), a conspicuous band in the cliffs at Hunstanton, where it is reduced to a thickness of 4 ft.

The sea in which the Gault was deposited extended farther than that under which the Lower Greensand was laid down, and in some parts of the country the Gault was spread out beyond the Lower Greensand. In our area, however, the Gault rests almost everywhere on the Lower Greensand and the line of junction is usually sharp (Pl. II B). The highest beds of the Lower Greensand contain no fossils, and their exact age cannot therefore be determined. But fossils usually occur almost throughout the Gault, and the frequent occurrence of ammonites enables zonal subdivisions to be established and detailed correlations to be made. By means of these close subdivisions some interesting facts have become known.

A comparison of the ammonite-zones below the Gault in this country with those abroad shows that the English series is incomplete: the lowest zones (comprising the Lower Albian of the Continent), with one exception, are missing. Whether these are represented by part of the unfossiliferous sands beneath the Gault clay is uncertain. The one Lower Albian subzone that is known to be present in this area (and is also found at a few other localities in England) is seen in the neighbourhood of Leighton Buzzard where it forms a sandy basement bed to the Gault. It is named after the ammonite *Leymeriella regularis*, which with other ammonites (*Leymeriella tardefurcata* and *Sonneratia kitchini*) occurs occasionally in gritty phosphatic nodules. Probably these nodules represent the more solid constituents of a bed that was originally formed on the spot, the lighter material having been washed away by current-action. Contemporary erosion was very active during the deposition of the Gault and in places has removed the larger part of the Lower Gault. This is evident from the lateral variation of the beds between the Lower Greensand and the Gault, the variation being due in some measure to shallow folding

FIG. 4. *Fossils from the Neocomian beds and the Lower Greensand.*

1. *Zeilleria woodwardi* Walker; 2. *Terebratella fittoni* Meyer; 3. *Terebratula praelonga* J. de C. Sowerby; 4. *Thetironia minor* (J. de C. Sowerby); 5. *Pecten* (*Neithea*) *atavus* Roemer; 6a, b. *Littorina upwarensis* Keeping; 7. *Opis neocomiensis* d'Orbigny; 8. *Nuculana scapha* (d'Orbigny); 9. *Hyposalenia wrighti* Desor; 10. Dorsal spine of *Asteracanthus ornatissimus* Agassiz. (Derived from the Kimmeridge Clay) (x$\frac{2}{3}$); 11. *Ceriopora nodosa* Keeping (x$\frac{3}{4}$); 12. *Raphidonema macropora* Sharpe (x$\frac{3}{4}$); 13. *Deshayesites fissicostatus* (Phillips) (x$\frac{2}{3}$); 14. *Plicatula carteroniana* d'Orbigny; 15. *Rhynchonella antidichotoma* Buvignier.

before erosion, so that lower beds (such as the *regularis* Subzone) remain as remnants in the hollows that escaped erosion. In places where they remain they form passage beds between the Lower Greensand and the Gault.

In sand-pits near Shenley Hill, north of Leighton Buzzard, lenticles of fossiliferous limestone have been found at the top of the Lower Greensand and underneath the Gault. These lenticles vary in size from 2 to 10 ft. or more in length and consist of tough limestone, pale-pink in colour, sometimes gritty, and containing scattered grains of smooth shining quartz, lydite and dark iron-oxide. They enclose an extensive suite of fossils, including the brachiopods *Terebratula capillata*, *Rhynchonella leightonensis*, *Terebratella menardi* var. *pterygotos*, and *Terebrirostra incurvirostrum*, the lamellibranchs *Septifer lineatus* and species of *Pecten* and *Lima*, occasional echinoids and gastropod shells, and the crinoid *Torynocrinus*. The ammonite *Leymeriella* has also been found in the limestone. Brachiopods are by far the commonest fossils and the whole assemblage bears a close resemblance to that of the basal part of the Lower Chalk, especially the Cornstones of Wiltshire.

Apart from the presence of the *regularis* Subzone, the rest of the Gault is similar to that developed in other parts of the country except for the change to the attenuated development of Red Rock at Hunstanton. In addition to the zones, two main divisions, Lower and Upper, are distinguished. Phosphatic nodules are scattered throughout but occur more frequently in layers at the base of both the Lower and Upper divisions. The Upper Gault clay, however, contains a much higher percentage (as much as 50 per cent) of carbonate of lime.

Among the fossils are bones of marine reptiles, numerous species of ammonites, *Hoplites dentatus*, in the Lower Gault, *Hysteroceras varicosum* in the Upper Gault, &c., the small belemnite *Neohibolites listeri*, the bivalved shells *Inoceramus concentricus*, *Inoceramus sulcatus*, *Nucula ovata*, *N. pectinata*, *N. bivirgata*, and *Plicatula gurgitis*, the univalved shells *Natica* (*Gyrodes*) *genti* and *Dentalium decussatum*, the brachiopod *Terebratula biplicata* and the coral *Trochocyathus angulatus*. The Upper Gault is distinguished not only by certain species of ammonites but also by the common shell *Inoceramus sulcatus*.

The Gault clay is used extensively for brickmaking and for the manufacture of tiles and pipes.

HUNSTANTON RED ROCK

At Hunstanton the Carstone is overlain by a conspicuous bed called the Hunstanton Red Rock or Red Chalk. Although these two beds, the Carstone and the Red Rock, are different in appearance, a mineral analysis shows that there is a gradual passage between them, the sandy constituents and

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FIG. 5. *Fossils from the Shenley Limestone and the Gault.*

1. *Nucula* (*Acila*) *bivirgata* J. Sowerby; 2. *Nucula ovata* Mantell; 3. *Natica* (*Gyrodes*) *genti* J. Sowerby; 4. *Hysteroceras varicosum* (J. de C. Sowerby); 5. *Inoceramus sulcatus* Parkinson; 6. *Inoceramus concentricus* Parkinson; 7. *Hoplites dentatus* (J. Sowerby); 8. *Dentalium decussatum* J. Sowerby; 9a, b. *Rhynchonella leightonensis* Lamplugh and Walker; 10a, b. *Terebrirostra incurvirostrum* (Lamplugh and Walker); 11a. b. *Terebratula capillata* d'Archiac; 12a, b, c. *Terebratella menardi* Lamarck, var. *pterygotos* Lamplugh and Walker; 13. *Leymeriella tardefurcata* (Leymerie) (x$\frac{3}{4}$).

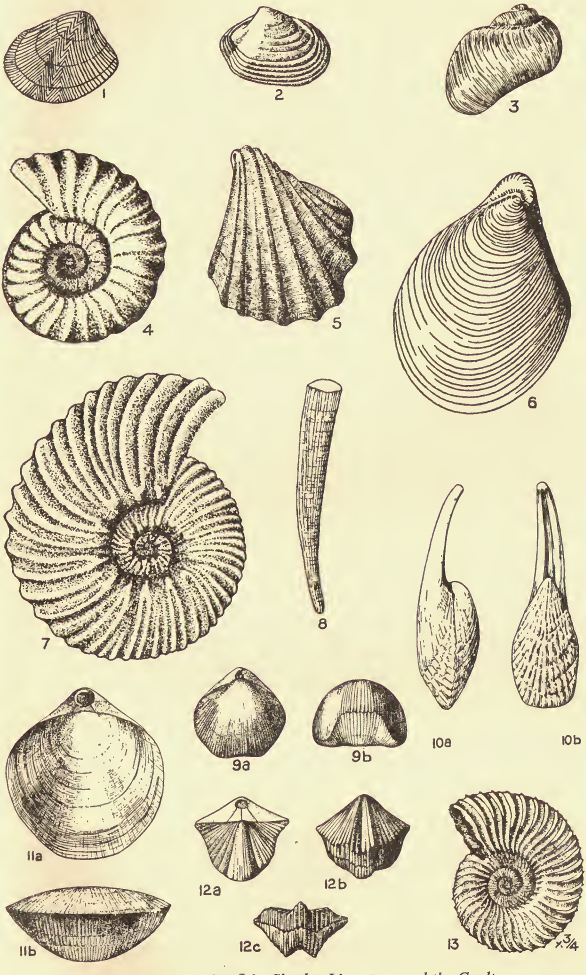

FIG. 5. *Fossils from the Shenley Limestone and the Gault.*

the distinctive heavy minerals of the Carstone continuing to the top of the Red Rock, but in diminishing amount. This is rather striking when compared with the evidence of the fossils, for these show no continuity. In the Carstone, fossils are restricted to the base, and only some 35 ft. of Carstone intervene between this horizon and the fossiliferous beds of Red Rock. But many ammonite-zones, represented in places by a few hundred feet of strata, are known to occur elsewhere between these two horizons. Evidently deposition was very slow and scanty here. The Red Rock as well as the Carstone is a condensed deposit and its fossils prove that it represents both Upper and Lower Gault elsewhere, for although it is only 4 ft. in thickness, all but 10 in. at the base is Upper Gault, and fossils representing zones of the Lower Gault have been found as semi-derived specimens in the lower part.

Three bands can be recognized in the Hunstanton Red Rock: the lowest is deep-red and gritty and contains abundant quartz pebbles; the middle is a rough nodular red limestone; and at the top is a bed of hard light-red or pink mottled limestone. The colouring of this deposit is probably due to red mud washed from lateritic material, the product of weathering of a contemporary land area.

The fossils of the Red Rock are similar to those of the Gault. Among the ammonites may be noted *Beudanticeras sphaerotum*, *Euhoplites ochetonotus* and *Hoplites canavariformis*. The small belemnites are common, and *Inoceramus sulcatus*, already mentioned as restricted to the Upper Gault, is found 10 in. from the base. A wide flat form of *Inoceramus* is also common—*Inoceramus anglicus*. One may note also that curious branching concretionary structures, formerly thought to be fossils and named *Spongia paradoxica*, are found at the top of the Red Rock. These occur also at the base of the overlying formation, the Chalk.

In parts of the country south of our area, the upper zones of the Gault are to a certain extent represented by sandy beds, known as the Upper Greensand. Such a sandy development has a very limited extent in our area: it can be traced for only a short distance in south Bedfordshire from Eddlesborough past Eaton Bray, and around Tilsworth and Wingfield. The bed is a fine yellowish-grey micaceous sand which passes up into a green glauconitic sand. Its maximum thickness is 20 ft. and only one species of fossil has been recorded from it, the small bivalved shell *Aucellina gryphaeoides*.

CAMBRIDGE GREENSAND

Towards the end of the time when the Gault was being deposited a local upward movement of the sea-floor brought the top zones of the Upper Gault

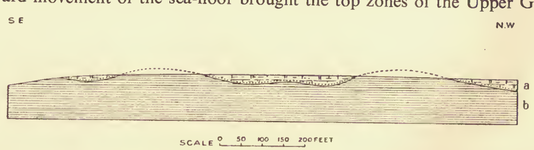

FIG. 6. *Diagrammatic section north-east of Haslingfield, Cambridgeshire.*
(From W. H. Penning and A. J. Jukes-Browne, 'The Geology of the Neighbourhood of Cambridge', *Mem. Geol. Surv.*, 1881, p. 37, Fig. 7.)
a. Chalk Marl. *b.* Gault.

within the range of marine erosion. Part of the newly-formed beds of Gault were removed and their heavier constituents, including the fossils, were rolled and redeposited. Under such conditions sedimentation was slow, fossils of slightly different ages became mixed, and a pebble bed was produced. In this manner the Cambridge Greensand was formed.

This bed is rarely as much as one foot in thickness, and consists of sandy and chalky marl with abundant phosphatic nodules at the base. As a rule the nodules are accumulated to a depth of 9 in., but where the bed rests on a hollowed surface the thickness may be 1 ft. The under surface of the bed rests sharply on the Gault; above, the bed passes up into the overlying Chalk Marl (Figs. 6 and 7). To a large extent the nodules are phosphatized casts of

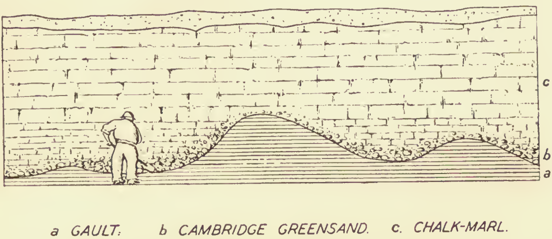

FIG. 7. *View of a coprolite pit near Horningsea, Cambridgeshire* (*now closed*). (After A. J. Jukes-Brown and W. Hill, 'The Cretaceous Rocks of Britain', vol. 2, *Mem Geol. Surv.*, 1903, p. 194.)

fossils; they are usually waterworn, sometimes bored by organisms, and frequently encrusted with small shells (*Dimyodon nilssoni*). Here and there among the nodules are extraneous rocks or erratics, varying in size from a pebble about the size of a hen's egg to a boulder about 1 ft. in diameter. Two boulders may be matched with a rock (paisanite) from Mynydd Mawr, in North Wales, others with Uriconian rocks from the Midlands and the Welsh borders, and two types of rock are unknown in the British Isles. The boulders were probably floated to the Cambridge district in the roots of trees, and they indicate the existence of land in North Wales (or some other place where paisanite occurred) and other areas in Cambridge Greensand times. It seems likely that some, but not all, of the erratics were first included in an earlier deposit, such as the New Red Sandstone, before they got to the Cambridge Greensand.

On account of their value in the manufacture of manures the phosphatic nodules (or 'coprolites' as they have been popularly called) were formerly dug extensively, a large number of pits having been opened up for the purpose along a tract about 50 miles in length, extending from Harlington in East Bedfordshire to Soham, south-east of Ely.

Abundant fossils, representing almost all classes of animals, have been found in the Cambridge Greensand; the majority are much eroded. Bones of reptiles are common and include several orders, among them being pterodactyls, saurians, and crocodiles; among the marine forms are *Polyptychodon* and *Ichthyosaurus*. Fish-remains include teeth of the sharks *Oxyrhina* and *Lamna* and bones of *Edaphodon*. Crabs and lobsters are represented by *Notopocorystes* [=*Palaeocorystes*] *stokesi*, *Necrocarcinus bechei* and *Enoploclytia dixoni*.

Ammonites are very common and many species, representing three zones, have been found. Among them are *Desmoceras latidorsatum*, *Puzosia sharpei*, *Anahoplites planus*, *Discohoplites coelonotus* and species of *Callihoplites*, *Lepthoplites*, *Pleurohoplites*, *Stoliczkaia*, and *Pervinquieria*. Of the univalved shells *Funis elongatus*, *Natica* (*Gyrodes*) *genti* and *Pleurotomaria allobrogensis* are typical, while common bivalved shells are *Aucellina gryphaeoides*, *Ostrea diluviana*, *Isognomon lanceolata*, and *Plicatula gurgitis*.

Among the brachipods are *Ornatothyris sulcifera*, *Rhynchonella sulcata* and *Terebratula biplicata*. There are several species of echinoderms, sponges, annelids (*Serpula umbonata*), and corals (*Micrabacia coronula*, *Trochocyathus conulus*, &c.), and the peculiar spherical hydrozoon *Parkeria* is also found.

CHALK

The deposits that have just been described are all included in the Continental term Albian, a name applied to a group of strata characteristically developed in the Department of the Aube, in France. Near the end of Albian times the strata being deposited in our area were the Gault, Cambridge Greensand, Upper Greensand, and the Red Rock—all formed under different conditions. These strata are succeeded by a more uniform formation, the Chalk. There is a gradual transition from the upper part of the Gault into a calcareous marl, similarly the Cambridge Greensand and the Upper Greensand also pass gradually upwards into a calcareous marl; in Norfolk the change from the Red Rock or its equivalent is abrupt. This change of sedimentation followed a gradual sinking of the sea-floor that continued with slight pauses for a long period. The subsidence took place over practically the whole of the area that is now the British Isles and affected parts of Europe as well, and continued until a great thickness of calcareous ooze had accumulated. This material, on consolidation, became the now-familiar Chalk.

The subsidence was at once widespread, and the resulting encroachment of the sea, being general, is referred to as the Cenomanian Transgression, because some of the deposits then formed can be correlated with the strata at Le Mans (Sarthe), of which the Latin name was Cenomanum.

On account of its great thickness (it attains a maximum of 1,400 ft. in Norfolk) and its regular lateral extent, the Chalk is the dominant formation in our area. It also gives the name to the group of formations, the Cretaceous System, of which it is the characteristic member (Latin, *creta*, chalk). The western boundary of the Chalk can be traced from the escarpment in Bedford-

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FIG. 8. *Fossils from the Red Chalk and the Cambridge Greensand.*

1. *Isognomon lanceolata* Geinitz; 2. *Pleurotomaria allobrogensis* Pictet and Roux; 3. *Parkeria spherica* Carter; 4. *Discohoplites coelonotus* (Seeley); 5. *Rhynchonella sulcata* Parkinson; 6a, b, c. *Micrabacia coronula* (Goldfuss) (x2); 7. *Serpula umbonata* (Mantell); 8. *Funis elongatus* Seeley; 9. *Dimyodon nilssoni* Hagenow; 10a, b. *Trochocyathus conulus* (Phillips) (b. calice enlarged); 11. *Ostrea diluviana* Linné; 12. *Euhoplites ochetonotus* (Seeley); 13. *Aucellina gryphaeoides* (J. de C. Sowerby) (x1½); 14. *Inoceramus anglicus* Woods.

A. HEATHLAND SCENERY. TUNSTALL, SUFFOLK.

B. SUFFOLK FARM-LAND NEAR SAXMUNDHAM.

(*For full explanation, see p. v.*)

A. NORTH-WEST CORNER OF THE CROMER RIDGE.

B. CONTORTED GRAVELS OF TERRACE OF THE RIVER CAM, GREAT SHELFORD, CAMBRIDGESHIRE.

(*For full explanation, see p. v.*)

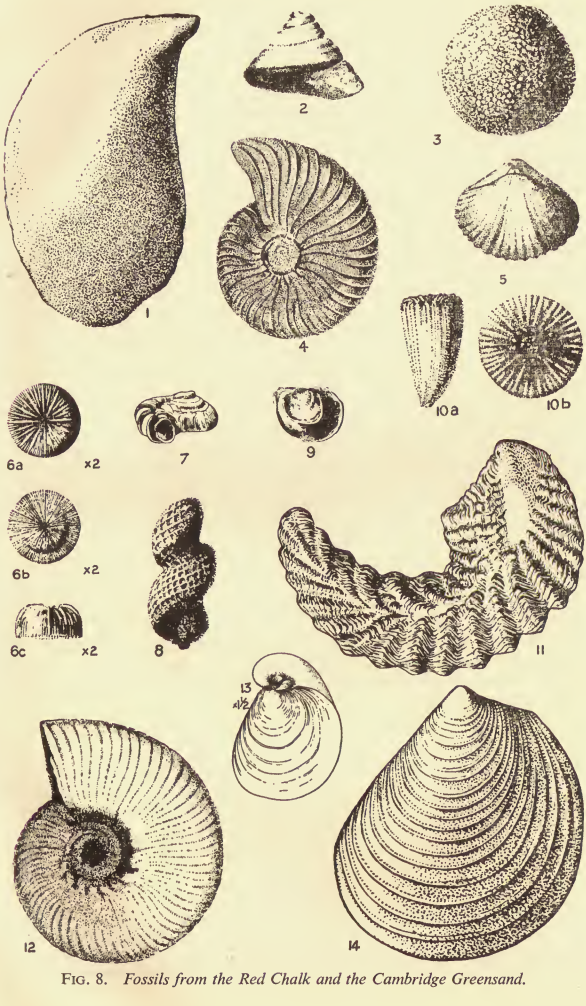

FIG. 8. *Fossils from the Red Chalk and the Cambridge Greensand.*

shire, to the north-east of Cambridge, where it borders the Fens and turns northwards to Hunstanton. It extends eastwards, either at the surface or beneath other formations, dipping at a slight angle.

The Chalk is entirely of marine origin, but only in the lowest beds is there any considerable trace of detrital constituents; the bulk of the formation is remarkable on account of the absence of terrigenous material. This may be partly due to land areas being far distant and partly to the prevalence of desert conditions on the land at that time. Temporary shallowing of the sea took place occasionally, as shown by evidence of current action (*e.g.* the Chalk Rock) and of certain fossils. Different opinions have been held as to the nature and origin of the Chalk. At one time it was regarded as a deep-sea deposit comparable with the Globigerina ooze of the Atlantic; and some investigators have thought it to be a chemical precipitate, while others have suggested that bacterial action was a considerable factor in its formation. The constitution of the Chalk has recently been under investigation by Mr. Maurice Black, with results that seem to have met with general acceptance. The facts now adduced agree better with a theory of primarily organic origin than with one invoking purely inorganic processes. Chalk varies considerably in constitution according to the proportion of the various components, the many varieties including the common soft chalks, gritty but friable chalk, and hard or nodular rock. Ordinary white chalk is a mixture of fine material (coccoliths, the excessively minute calcareous bodies produced by planktonic algae, and their disintegration products) and a varying proportion of shell-debris and foraminifera, the coarser fragments being embedded in a matrix of coccolith material. Coccoliths are present in vast numbers and in all stages of disintegration down to individual component crystals. The electron microscope shows that the finest particles of the matrix are of the same order of size as the individual crystals of the associated coccoliths, and the shape of the grains also varies with horizon according to the prevalent type of coccolith. Modern precipitated oozes, in contrast, contain scarcely any trace of coccoliths and relatively little shell material, their finer fractions having an abundance of minute aragonite crystals. Microscopic examination of chalk from certain horizons also shows a large proportion of minute spherical bodies called 'spheres'. These 'spheres' are presumably organic structures, but their exact nature is problematical; where they are abundant the chalk is apt to be rather hard or nodular.

The various differences in lithology observable in the formation were the basis of the first main divisions (Lower, Middle and Upper) that were established. A system of zonal subdivisions based on the occurrence of fossils is also employed. Many fossils have a definite range in the Chalk and can therefore be used as indexes to the successive stages of the animal-population of the sea on the bed of which the Chalk was deposited.

Lower Chalk

This comprises two chief subdivisions, the Chalk Marl below and the Grey Chalk above. Its total thickness is about 200 ft. in Bedfordshire, 170 ft. in Cambridgeshire, and 125 ft. at Stoke Ferry in Norfolk, from which place it decreases rapidly northwards, being reduced to 56 ft. at Hunstanton.

In Bedfordshire and Cambridgeshire the Chalk Marl (70 to 80 ft.) is a soft greyish marl, becoming hard in the upper part. In Norfolk, south of Stoke Ferry, it consists of alternating hard and soft beds (75 ft.), but north of that locality it thins out and at Hunstanton it is represented by only 18 ft. of hard greyish-white chalk with a bed of green-coated nodules near the base. At the last-named place the abrupt change from the Red Rock to the Lower Chalk has already been referred to. The lowest layer of the Chalk here is the Sponge Bed ($1\frac{1}{2}$ ft.), a hard white chalk with the same branching concretionary bodies that are present in the top layer (1 ft.) of the Red Rock below. Between these two layers is a thin irregular seam of red clayey and ferruginous mud. Mineral analysis of the Red Rock shows a peculiar assemblage of ' heavy ' minerals which are not present in the Sponge Bed. The two beds thus differ in lithology, but the fossils of the top layer of Red Rock and those of the Sponge Bed are practically identical. This seems to indicate that the peculiar type of sedimentation that produced the Red Rock during Albian times in this neighbourhood continued for a short period in early Cenomanian times.

Above the Chalk Marl is a well-marked rock-bed, the Totternhoe Stone, known in Cambridgeshire as the Burwell Rock (Figs. 9 & 10). Of a thickness

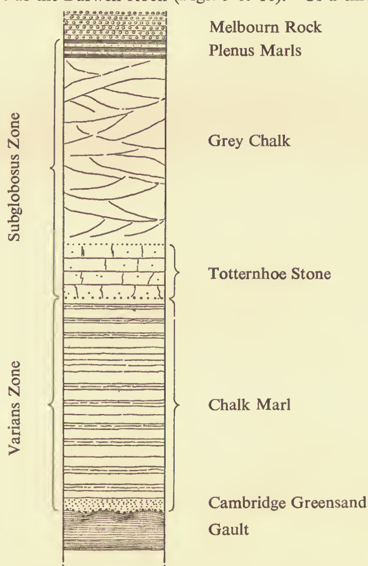

FIG. 9. *Divisions of the Lower Chalk near Cambridge.*
Scale: 50 ft. to 1 inch. (After H. J. Osborne White, ' The Geology of Saffron Walden ', *Mem. Geol. Surv.*, 1932, p. 21 ,Fig. 7.)

of 22 ft. in Bedfordshire, this bed becomes thinner to the north-east. At Burwell it is 20 ft. in thickness, at Stoke Ferry (Norfolk) 5 ft., and at Hunstanton only 2 feet. It is a light brownish grey chalk, which occurs in massive beds with numerous green-coated nodules at the base. On account of the compact nature of the beds, especially in the upper part, it has been used as a building stone, but it weathers badly and has been superseded even for indoor work. As a water-bearing stratum it is of some importance, and at various places springs break out along the line of junction between this and the underlying Chalk Marl.

The beds of Lower Chalk above the Totternhoe Stone are known as the Grey Chalk, although distinctly white in the upper part. They are tough and blocky, and in Cambridgeshire they show curiously-curved divisional lines due to irregular jointing. In Norfolk the Grey Chalk is mostly thin-bedded and platy.

Forming the upper limit of the Lower Chalk throughout the area are the Belemnite Marls, of an average thickness of 3 ft. These marls take their name from the occurrence (restricted to this layer) of the belemnite *Actinocamax plenus*; they usually consist of an upper and a lower layer of grey laminated marl separated by hard white limestone.

Fossils are to be found almost throughout the Lower Chalk and are fairly common in the basement bed of the Totternhoe Stone; they include remains of fish, ammonites, shells of mollusca and brachiopods, crustacea, echinoids, corals, and worm-tubes. Fishes are represented commonly by detached teeth of sharks and rays (*Lamna*, *Ptychodus*, etc.). Among the ammonites the genera *Schloenbachia* and *Mantelliceras* are characteristic of the Chalk Marl, the usual species being *Schloenbachia varians* and *Mantelliceras mantelli*. In the Grey Chalk most of the ammonites belong to the genus *Acanthoceras* and this division is characterized by the echinoid *Holaster subglobosus*. Typical lamellibranchs (bivalved shells) of the Lower Chalk are *Inoceramus crippsi*, *Plicatula inflata*, and *Lima globosa*. Oyster-shells of several species occur, conspicuous among them being the sharply-folded *Ostrea diluviana*. *Ostrea vesicularis* frequent in the upper part of the Lower Chalk. Pectens are common, *Pecten* (*Entolium*) *orbicularis* having a long range; and one species, *Pecten* (*Chlamys*) *fissicosta*, is typical of the Totternhoe Stone. Several species are to be found, among them *Ornatothyris sulcifera* and other species of that genus, *Rhynchonella grasiana*, *R. mantelliana* and *R. martini*. Among the univalved shells are species of *Pleurotomaria*, *Trochus* and *Turbo*. Representatives of the echinoids include *Discoidea* and *Holaster*.

Two broad zonal divisions have been established in the Lower Chalk. The lower zone, named after the ammonite *Schloenbachia varians*, corresponds with the Chalk Marl. Above, and including the Totternhoe Stone as its basal member, is the Zone of *Holaster subglobosus*, which ranges up to the Belemnite Marls.

From an economic point of view the Chalk Marl is of some importance; its constitution is highly suitable for the making of cement, and large pits have been opened for this purpose, especially in the neighbourhood of Cambridge. It forms also a rich tract for agricultural purposes.

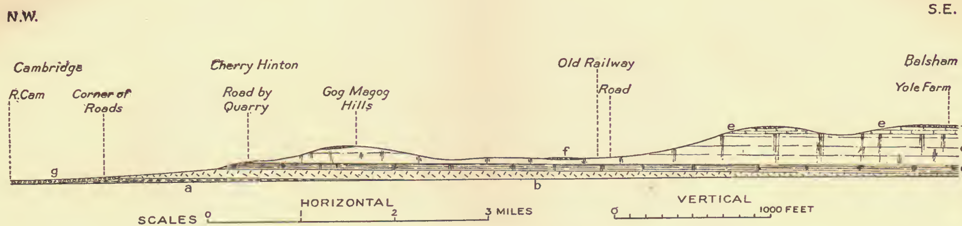

FIG. 10. *Section from Cambridge to Balsham.*

(After A. J. Jukes-Browne and W. Hill, 'The Cretaceous Rocks of Britain', *Mem. Geol. Surv.*, 1903, p. 201, Fig. 48.)

a. Gault.
Lower Chalk } *c.* Subglobosus Zone. *b.* Varians Zone.
d. Middle Chalk.
f. Boulder Clay.
e. Upper Chalk.
g. Valley Gravel.

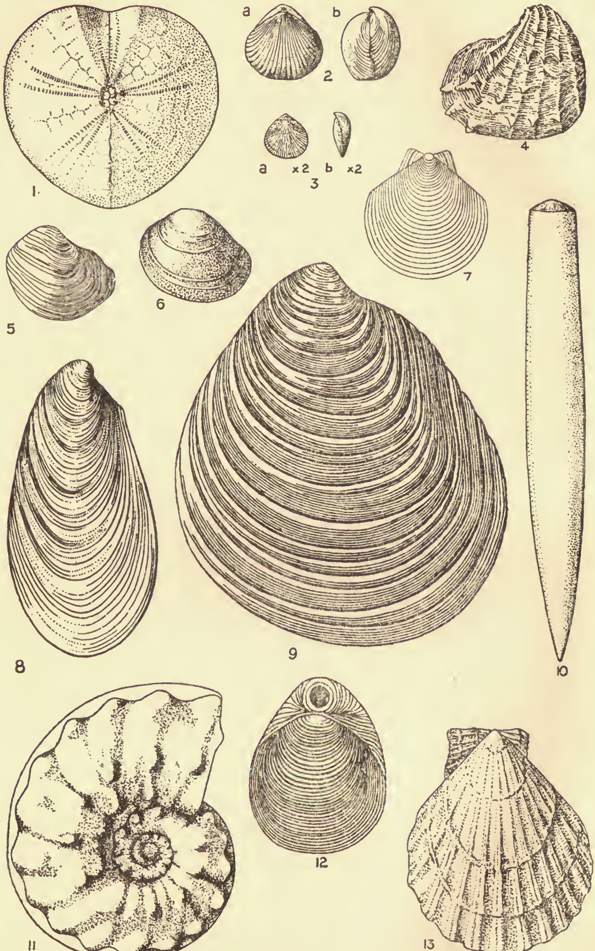

FIG. 11. *Fossils from the Lower and Middle Chalk.*

Middle Chalk

Like the Lower Chalk this division becomes thinner to the north. Of a thickness of 220 ft. in Bedfordshire it is reduced to less than 100 ft. in Norfolk. Throughout the area its bottom bed is the Melbourn Rock, a very hard yellowish rocky chalk full of small nodules; its thickness is 10 ft. in Bedfordshire but less in Cambridgeshire and Norfolk. The upper limit of the Middle Chalk is marked approximately by another rock bed, the Chalk Rock, to be referred to as part of the Upper Chalk. Between these two rock-beds the Chalk varies in lithology, and flint (not developed in the Lower Chalk, where the silica is dispersed and not aggregated) occurs in quantity in the upper part. The flint in the famous mines at Brandon (Suffolk) is worked at an horizon just below the top of the Middle Chalk.

The commonest fossils of the Middle Chalk are shells of brachiopods and lamellibranchs, and ' tests ' of echinoids. Two zonal divisions have been named after two small species of brachiopods: the lower is characterized by a globose, plainly-ribbed form (*Rhynchonella cuvieri*), and the upper by a smaller and flatter form with fine divergent ribs (*Terebratulina lata*). Two common species of lamellibranchs may be noted: *Inoceramus labiatus*, restricted to the lower zone, and *Inoceramus lamarcki* characteristic of the higher zone. Among the echinoids are *Conulus subrotundus*, *Discoidea dixoni*, and *Hemiaster minimus*. The ' heart-urchin ' *Micraster* makes its first appearance in the upper zone of the Middle Chalk, being represented by *Micraster corbovis*. Another echinoid, *Echinocorys scutatus*, is also found; its occurrence being notable because it rarely occurs below the Upper Chalk in other parts of the country.

Upper Chalk

At or near the base of this division is a development of yellowish nodular chalk, known as the Chalk Rock which attains a maximum thickness (including alternating bands of normal chalk) of 15 feet. In the southern part of our area this bed is conspicuous by reason of its including green-coated nodules. The Chalk Rock contains a peculiar assemblage of fossils, mostly casts and moulds of shells, known as the *reussianum* fauna, being named after the loosely-coiled ammonoid *Hyphantoceras reussianum*.

The conditions that gave rise to the development of Chalk Rock (shallowing of the sea and the action of currents) were repeated very shortly, for higher in the succession is another nodular band—the Top Rock—about 1 ft.; occasional representatives of the *reussianum* fauna have also been found in this.

In Bedfordshire and Cambridgeshire there is very little Chalk above the Chalk Rock, denudation having removed the higher beds. In Norfolk, however, the Upper Chalk is thicker than in any other part of the country and the highest horizon of the Chalk in Great Britain is found at Trimingham. The bulk

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FIG. 11. *Fossils from the Lower and Middle Chalk.*

1. *Holaster subglobosus* (Leske); 2 a, b. *Rhynchonella cuvieri* d'Orbigny; 3 a, b. *Terebratulina lata* Etheridge (x2); 4. *Plicatula inflata* J. de C. Sowerby; 5. *Ostrea vesicularis* Lamarck; 6. *Lima globosa* J. Sowerby; 7. *Pecten* (*Entolium*) *orbicularis* J. Sowerby; 8. *Inoceramus labiatus* (Schlotheim); 9. *Inoceramus crippsi* Mantell; 10. *Actinocamax plenus* (Blainville); 11. *Schloenbachia varians* (J. Sowerby); 12. *Ornatothyris sulcifera* (Morris and Davidson); 13. *Pecten* (*Chlamys*) *fissicosta* Etheridge.

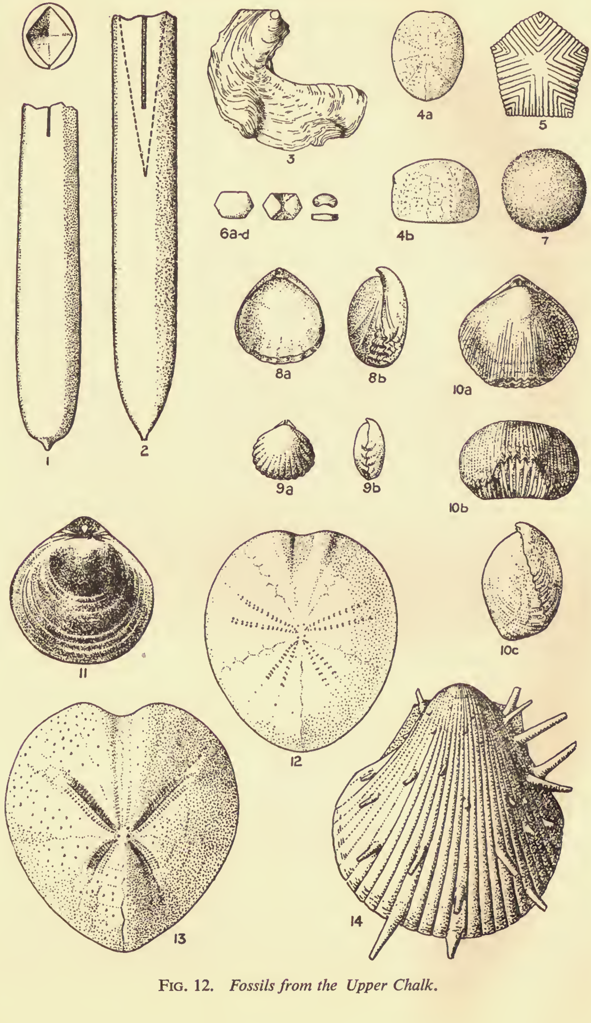

FIG. 12. *Fossils from the Upper Chalk.*

of the Upper Chalk is pure, soft limestone, white or cream-coloured and sometimes stained slightly yellow. Flint occurs throughout the Upper Chalk; it appears in the form of finger-shaped pieces, as large nodules, sometimes set in regular courses, or as thick tabular layers. Near Norwich flint takes the form of the familiar paramoudras (the name was introduced from Ireland and was probably derived from Erse words meaning ' sea pears '), large cylindrical masses from about 1 to 2 ft. in diameter and as much as 4 ft. in height and hollow like a pipe. In their natural position in the Chalk, the tubular cavity is vertical. Flint is impure cryptocrystalline silica formed, after the Chalk was deposited, by the separation of the silica contained therein (derived from the skeletons of sponges) into masses, sometimes around sponges as nuclei.

Fossils are common and the species numerous, each zonal division having its distinctive assemblage. In the lower zones the echinoid *Micraster* is distinctive, and certain parts of its shell (or ' test ') show progressive modification when traced through successively higher horizons; higher up, detached plates of crinoids (*Uintacrinus* and *Marsupites*) mark definite horizons of limited vertical range. Then come two zones distinguished by species of belemnites; first is that of *Actinocamax quadratus*, a belemnite with a characteristic square outline to the tapering cavity at the broad end, and above is that of *Belemnitella mucronata*, a form that has a well-developed pointed end. The last-named zone is exposed in numerous quarries near Norwich. As already noted, the highest beds are present only at Trimingham; they represent a zone characterized by a small oyster with a crescentic outline and crinkled margin—*Ostrea lunata*. The echinoid *Echinocorys scutatus* ranges throughout the Upper Chalk and exhibits variations in shape that generally correspond with horizons; *Offaster pilula* has been recorded from both the belemnite zones; while *Holaster planus* is rarely found above the lowest zone of this division.

The fossils already mentioned are only a few of the diagnostic forms. Many hundreds of different species have been found, and most of the principal divisions of the animal kingdom are represented. Ammonites, which are fairly common in the Lower Chalk and can be used as indexes of horizon, are too infrequent in the Middle and Upper Chalk to be used as a means of subdivision. Gastropods also occur with some frequency in the Chalk Marl; a different assemblage is found in the Chalk Rock, and a distinct fauna in the high zone around Norwich, where they are found chiefly inside the shells of *Echinocorys*. Lamellibranch shells are very common and are found throughout the Chalk; *Ostrea*, *Pecten*, and *Spondylus* are well represented, while *Inoceramus*, besides being the most common, is of zonal value, certain species being typical of different horizons. Brachiopod shells are also found throughout the formation, the usual forms being *Rhynchonella* and Terebratulid shells (*Gibbithyris*,

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FIG. 12. *Fossils from the Upper Chalk.*

1. *Actinocamax quadratus* (Defrance); 2. *Belemnitella mucronata* (Schlotheim); 3. *Ostrea lunata* Nilsson; 4 a, b. *Offaster pilula* (Lamarck); 5. *Marsupites testudinarius* (Schlotheim) (single plate); 6 a-d. *Uintacrinus socialis* Grinnell (a, b, outer and inner views of plate; c, d, top and side views of arm ossicle); 7. *Porosphaera globularis* (Phillips); 8 a, b. *Rhynchonella limbata* (Schlotheim) var. *lentiformis* S. Woodward; 9. *Rhynchonella reedensis* Etheridge; 10 a, b, c. *Rhynchonella plicatilis* (J. Sowerby); 11. *Carneithyris carnea* (J. Sowerby); 12. *Holaster* (*Sternotaxis*) *planus* Mantell; 13. *Micraster coranguinum* (Leske); 14. *Spondylus spinosus* (J. Sowerby).

etc.). The *mucronata* Zone around Norwich has yielded large numbers of brachiopods, among them *Rhynchonella limbata* and *Carneithyris carnea*. Sponges (*Porosphaera globularis*, *Ventriculites*, &c.) are frequent in the Upper Chalk and are often enclosed in flint.

Throughout the area the Chalk has been quarried for lime-burning, while many churches in East Anglia are built of flint, the parish church at Cromer being a fine example. Until recently, gun-flints have been made at Catton and Whitlingham, in Norfolk, while the Brandon mines are said to produce the finest flint in England.

IV. EOCENE STRATA

AFTER THE LONG period of steady subsidence during which the Chalk was deposited the whole area was raised as a land-mass and was acted upon by the agents of denudation; it was also subjected to gentle tilting and folding (Fig. 13). Eventually the south-eastern part of England was invaded by a sea which laid down some of the earliest deposits of the Tertiary Era. These deposits are termed Eocene because the fossils in them have affinities with present-day forms of life (Greek, *eos*, dawn; *kainos*, recent).

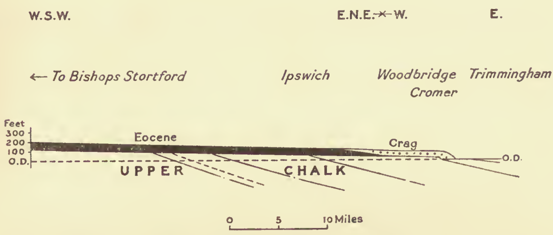

FIG. 13. *Diagrammatic section showing the lateral transgression of the Upper Chalk by Eocene and Crag deposits.*

(After P. G. H. Boswell, *Quart. Journ. Geol. Soc.*, vol. lxxi, 1916, p. 546, Fig. 3.)

Meanwhile, considerable geographic changes had taken place since the deposition of the Chalk, for the Eocene beds are mostly sands and clays, and present a marked contrast with the familiar white limestone of the Chalk (Pl. III B). Notable changes in the forms of life had also taken place, and the contrast between the fossils of the Eocene and those of the Chalk is as marked as the nature of the beds which contain them. With the end of the Secondary Era the great reptiles like the ichthyosaurs and the dinosaurs disappeared; the ammonites died out; true birds took the place of flying reptiles. In the Tertiary Era mammals became the dominant vertebrates, while invertebrates such as the mollusca and corals became more akin to present-day forms.

The Eocene sea, at first very shallow, occupied the southern part of our area and its margin evidently extended north-eastwards, but subsequent denudation of its deposits has largely removed the traces of its former extent, and Eocene strata occupy the surface only in restricted areas. The main outcrop of Eocene strata is situated between the rivers Stour and Orwell, and extends from Sudbury to the coast. North-east of this district the beds are overlain by later deposits and are exposed only in the river-valleys. Three divisions, which take their names from places in other parts of the country where they are best developed, are present in our area.

THANET BEDS

These beds include sandy loams, clays and clayey sand, of an olive-brown, green, and grey or pink colour. Usually there is a bed of large green-coated pitted flints at the base. Along the main outcrop (between Sudbury and the Gipping Valley) the total thickness does not exceed 14 ft., but the formation thickens underground eastwards. The beds are not exposed east of the Gipping Valley, but have been encountered in borings in East Suffolk; they rest always on the Chalk.

READING BEDS

The Reading Beds are more variable in character than the Thanet Beds and their distribution is much wider. In the area just mentioned they overlie the Thanet Beds and consist of reddish and nearly white sharp sand with lenticular masses of brown plastic clay, or of coloured and mottled clay. In thickness they do not exceed 20 ft. and are in most places considerably less. Towards the north-east and south-west, as shown by boring records, the Reading Beds thicken considerably. Remnants of the previous extension of the beds occur as outliers in Bedfordshire, at Caddington, Kensworth, and Studham. The formation also extends beneath the Crag deposits in parts of Norfolk, 40 ft. of sands and clays having been proved in a boring at Yarmouth, 430 ft. beneath the surface. No fossils have been recorded from the Reading Beds in East Anglia. Evidently the deposition of these beds followed an elevation of the sea floor, because in our area they are of fluviatile origin.

Scattered over the southern part of Suffolk are angular blocks of sandstone called Sarsens or greywethers. Their distribution and their mineral constitution make it evident that they were derived from the sands of the Reading Beds.

LONDON CLAY

With the deposition of this formation more settled and tranquil conditions set in, and the whole of the south-east of England sank steadily as an area not far from the mouth of a big river. Fossils found in the London clay indicate a subtropical climate.

At the base of the formation in most places is a basement-bed of rounded black flint pebbles. Associated with the pebbles is usually a foot or two of grey sand in which sharks' teeth and fragile shells are to be found. The main mass of the London Clay is a bluish-grey clay which weathers brown on exposure. In places it contains septaria, or nodular concretionary masses of clayey limestone (cement-stones), formerly used for the manufacture of cement.

The formation is exposed beneath the Crag at Felixstowe and Bawdsey. It comes to the surface also in the Deben Valley below Woodbridge, along the Orwell and its tributaries below Ipswich, and along the Stour and its tributaries below Boxford. Only the lower part of the formation is present in the main area of Tertiary beds, a considerable thickness having been removed by erosion. A well boring at Orford, however, proved a thickness of 130 ft.

Only a few fossils have been found in the London Clay of the area; they include the shells *Natica glaucinoides*, *Cyprina planata*, and *Pitaria tenuistriata*. Occasionally teeth of the shark *Odontaspis macrota* and tree-trunks with attached *Modiolus* are found. Many years ago remains of mammals (marsupials, Cheiroptera and *Hyracotherium*) were found in sand at the base of the London Clay at Kyson, near Woodbridge. Outside the area, however, the occurrence in this formation of the remains of turtles, sharks, nautili, crabs, a variety of shells, and fragments of palm-trees, provides ample evidence of the conditions of the times.

Several divisions of Tertiary strata are not represented in the area, and a long interval of time, accompanied by great geographical changes, during which these strata were laid down elsewhere, intervened between the formation of the London Clay and the next series of marine deposits in East Anglia.

V. CRAG DEPOSITS

During the interval just mentioned most of the area stood above sea-level, but eventually this land was partly submerged beneath a precursor of the present North Sea. The whole area was unstable, and movements of the sea-floor controlled the nature and distribution of the next series of marine deposits that are present in East Anglia. These deposits, consisting chiefly of shelly sands, pebbly gravels and sand, extend over the eastern parts of Norfolk and Suffolk (Fig. 14), and the term 'Crag', a word used locally for any shelly sand is commonly employed to denote them. They are largely covered by beds of glacial origin (p. 58).

The fossils preserved in the Crag show a strong resemblance to present-day forms of life and were accordingly referred to the Pliocene period (Greek *pleion*, more; *kainos*, recent); several local subdivisions are now recognized. These subdivisions will be considered in order of age, but first a detritus-bed, found at the base of several divisions of the Crag in Suffolk, should be noticed. This deposit, sometimes called the Nodule Bed, the Suffolk Bone Bed, or (erroneously) the Coprolite Bed, is impersistent and of inconsiderable thickness (3 in. to 2 ft.), but is of interest because of the varied nature of its constituents. Of these a proportion are nodules rich in lime phosphates, a composition that gave them considerable commercial value when used for agricultural purposes. They were formerly dug from pits situated in the area that would be enclosed by lines drawn from Ipswich to the sea at Orford and to Walton-on-the-Naze. In addition to the phosphatic nodules the bed contains bones and teeth (rolled, water-worn and phosphatized, and many derived from the London Clay), large flints from the Chalk, pieces of igneous rocks, Jurassic rocks and fossils and box-stones. The box-stones, rolled nodules of brownish sandstone which frequently enclose casts and moulds of shells, are notable because they represent strata (probably of Miocene or Oligocene age) of a kind not otherwise present in this country.

Materials of very different geological ages are thus represented in this agglomeration. The constituents (many from far-distant places) came from different directions, mostly from the north, probably at different times and by different means; but all were swept up at the bottom of the Crag sea. In regard to the large flints from the Chalk, a suggestion (first made by Lyell and supported by later observers) that they were brought into the area by floating ice is significant, because they are not found beneath the oldest divisions of the Crag, but occur in the detritus-bed beneath later divisions, in which fossils show that the seas were becoming colder. The gradual refrigeration culminated in the Glacial Period and thus continued after the Pliocene through most of the next epoch, the Pleistocene (Greek, *pleistos*, most; *kainos* recent). The changes in the fossils were also gradual, and there has long been uncertainty as to where the boundary between the Pliocene and the Pleistocene should be fixed. Until recently all the Crag was included in the Pliocene, but in accordance with a recommendation of the International Geological Congress only the Coralline Crag is now regarded as of that age in East Anglia.

PLIOCENE: CORALLINE CRAG

The Coralline Crag consists essentially of shelly sands and beds made up almost entirely of finely broken shells or of polyzoa (or bryozoa); in some

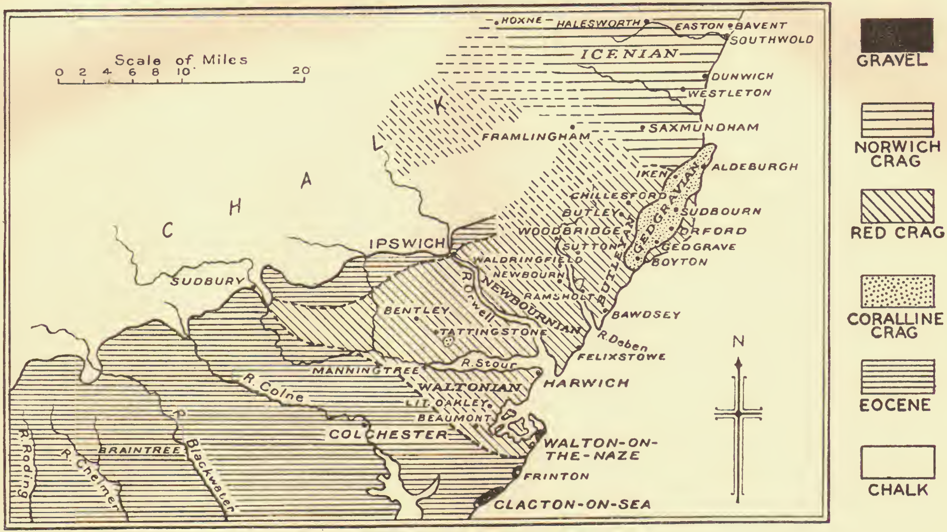

FIG. 14. *Map showing the relative areas occupied by the different Zones of the East Anglian Crag deposits.*
(After F. W. Harmer, 'The Pliocene Mollusca', (*Palaeont. Soc.*), vol. 2, part 1, 1920, p. 497, Fig. 4, and modified after Woodland, the probable extension of the Red Crag and the Norwich Crag (covered by Drift) being indicated by broken lines.)

places layers of perfect shells occur. Its total thickness is about 60 feet. The name was given because of the abundance of ' corals ' found in it; and although these organisms were subsequently determined as polyzoa the name has been retained. As a whole this Crag is whitish or slightly yellow in colour, and originated as sand-banks in a shallow sea; it was mostly laid down under strong currents, as is shown by oblique bedding and the abundance of polyzoa. At certain localities the upper beds have been decalcified by percolating water and hardened by the deposition of secondary carbonate of lime and iron oxide, thus forming a rock-bed (the ' Bryozoan rock-bed ') that can be quarried like a freestone. The main mass of the Coralline Crag occupies a tract between Gedgrave Marshes and Aldeburgh, Suffolk (Fig. 16); small patches occur near Tattingstone, Boyton, Ramsholt and Sutton.

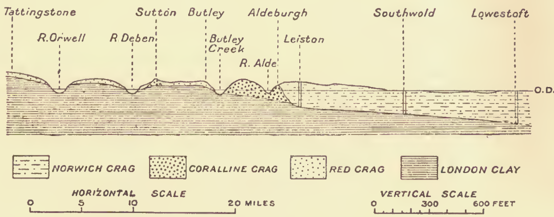

FIG. 15. *Section from Tattingstone to Lowestoft, showing the comparative thickness of the Red Crag and of the Norwich Crag of East Suffolk, as also the rapid thickening of the latter northward.*

(After F. W. Harmer, *Quart. Journ. Geol. Soc.*, vol. lvi, 1900, p. 734, Fig. 5.)

Among the many species of polyzoa in this Crag are *Alveolaria semiovata* and *Meandropora* [*Theonoa*] *aurantium*. Shells occur in abundance and include the bivalves *Ostrea cochlear*, *Chlamys opercularis*, *Chlamys tigrinus*, *Glycymeris glycymeris*, *Cardita senilis*, *Astarte incerta* and *Cyprinia islandica*. Among the univalved shells are *Scala* (*Nobiliscala*) *foliacea*, and *Trochus* (*Gibbula*) *tricariniferus*. A common echinoid is *Echinus woodwardi*; the corals include *Flabellum woodi*; the brachiopod *Terebratula maxima* (=*grandis*) is common, as also is the barnacle *Balanus concavus*.

The fossils as a whole show that the Coralline Crag sea was fairly warm and that there must have been free communication with the south. Some of the species are still living in the Mediterranean. Fossils found by Alfred Bell at Boyton, however, showed that several boreal genera (among them *Bela*, *Purpura*, *Trophon* and *Neptunea*) appeared there for the first time in East Anglia; he therefore concluded that the Crag at Boyton was newer than that of the main mass, and he correlated the occurrence with certain earth-movements that were beginning to affect the Crag area. These movements had the effect of opening the area to northern waters and gradually closing the connexion with the south. Thus began the gradual change in the assemblage of fossils in the various divisions of the Crag, the percentage of northern species increasing and the southern species diminishing. The subdivision of the East Anglian Crag is based on the proportion of northern and southern species, and the subdivisions are

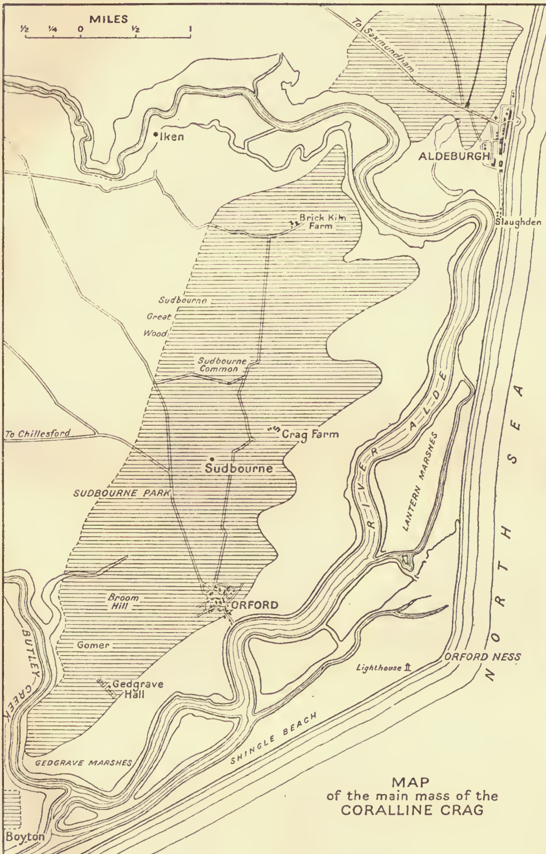

FIG. 16. *Map of the main mass of the Coralline Crag.*
(After F. W. Harmer, *Quart. Journ. Geol. Soc.*, vol. liv, 1898, p. 326, Fig. 4.)

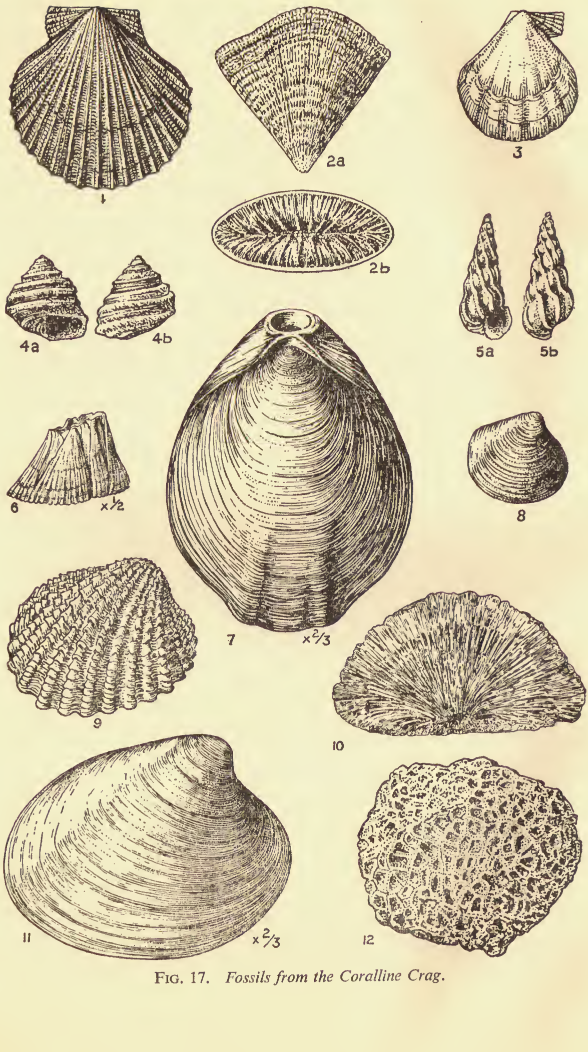

FIG. 17. *Fossils from the Coralline Crag.*

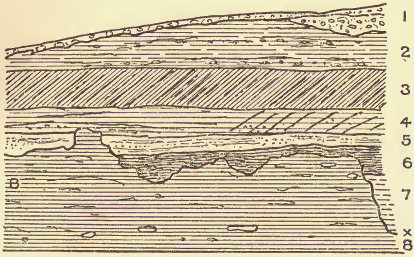

FIG. 18. *Section in pit at Park Farm, Tattingstone, Suffolk.*

(After J. Prestwich, *Quart. Journ. Geol. Soc.*, vol. xxvii, 1871, p. 342, Fig. 24.)

1. Drift: coarse gravel

Red Crag:

2. Ochreous sand, with seams of ironstone, etc.
3. Crag with a few coprolites
4. Light-coloured Crag
5. White sand
6. Brown loam
7. Not described

8. Coralline Crag

x. Face of old cliff; depth not shown

Scale about 12 ft. to 1 inch

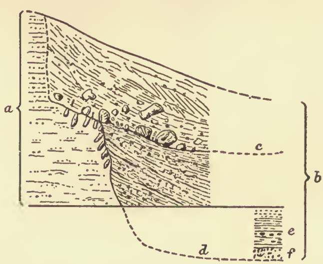

FIG. 19. *Section in the Bullockyard Pit, Sutton, Suffolk.*

(After J. Prestwich, *loc. cit.*, p. 340, Fig. 21.)

(a) Coralline Crag. (b) Red Crag. (c) Upper shore-line with blocks of Coralline Crag, flints, coprolites and shells above it. (d) Lower shore-line. (e) Shells of *Mytilus edulis*, almost all with both valves. (f) Bed of coprolites and large flints.

FIG. 17. *Fossils from the Coralline Crag.*

1. *Chlamys* (*Aequipecten*) *opercularis* (Linné); 2 a, b. *Flabellum woodi* Edwards and Haime; 3. *Chlamys* (*Palliolum*) *tigrinus* Müller; 4, a. b, *Trochus* (*Gibbula*) *tricariniferus* S. V. Wood; 5 a, b. *Scalaria* (*Nobiliscala*) *foliacea* (J. Sowerby); 6. *Balanus concavus* Brown (x½); 7. *Terebratula maxima* Charlesworth em. Muir-Wood (x⅔); 8. *Astarte incerta* S. V. Wood; 9. *Cardita senilis* (Lamarck); 10. *Theonoa aurantium* (Milne-Edwards) (as seen in section); 11. *Cyprina islandica* (Linné) (x⅔); 12. *Alveolaria semiovata* Busk.

FIG. 20. *Section in the Bullockyard Pit, Sutton, at right angles to Fig.* 19.
(After J. Prestwich, *loc. cit.*, p. 340, Fig. 22.)

Red Crag with large blocks of Coralline Crag, the larger may weigh more than one ton; (1) must have fallen before, and (2) after the deposition of the bed (3). Upper shore-line (4).

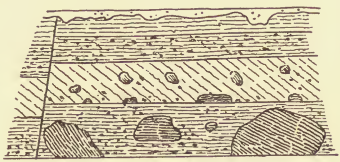

FIG. 21. *Section in the Bullockyard Pit, Sutton, on Western part of the ridge.*
(After J. Prestwich, *loc. cit.*, p. 340, Fig. 23.)

Red Crag with many blocks of Coralline Crag and some flints and phosphatic nodules. Section of the lower shore-line on the western side of the reef.

named after the localities where they are typically developed. In the case of the Coralline Crag two substages are recognized—Gedgravian and Boytonian.

The earth-movements which set in after the formation of the Coralline Crag were a sequence of foldings which from time to time shifted the area of deposition and formed a series of shallow-water bays or inlets which moved northwards as successive Crag deposits were laid down. These deposits have been named, after the prevailing colour, the Red Crag.

Considerable erosion followed the deposition of the Coralline Crag, and only patches of that Crag now remain. Also, the fossils of the Red Crag indicate the arrival of a number of boreal species. These facts, combined with the evidence of a strong unconformity between the two Crags (for where they occur together the Red Crag is either banked against the Coralline Crag or else rests on an eroded surface of it) (Figs. 18-21) provide a good reason for choosing the unconformity as the boundary between the Pliocene and Pleistocene deposits.

FIG. 22. *Fossils from the Red Crag.*

1. *Neptunea despecta* (Linné) (x$\frac{2}{3}$); 2a, b. *Purpura tetragona* (J. Sowerby) (x$\frac{3}{4}$); 3. *Neptunea contraria* (Linné) (x$\frac{2}{3}$); 4. *Nassa reticosa* (J. Sowerby); 5. *Nassa* (*Hima*) *granulata* J. Sowerby (x2); 6. *Nucella* [*Purpura*] *lapillus* Linné; 7. *Scaphella lamberti* (J. Sowerby) (x$\frac{2}{3}$); 8. *Dosinia exoleta* (Linné) (x$\frac{3}{4}$); 9. *Pholas* (*Barnea*) *cylindrica* J. Sowerby; 10. *Astarte obliquata* J. Sowerby; 11 a, b. *Aloidis* [*Corbulomya*] *complanata* (J. Sowerby); 12. *Laevicardium parkinsoni* J. Sowerby (x$\frac{2}{3}$); 13. *Glycymeris glycymeris* (Linné) (x$\frac{2}{3}$).

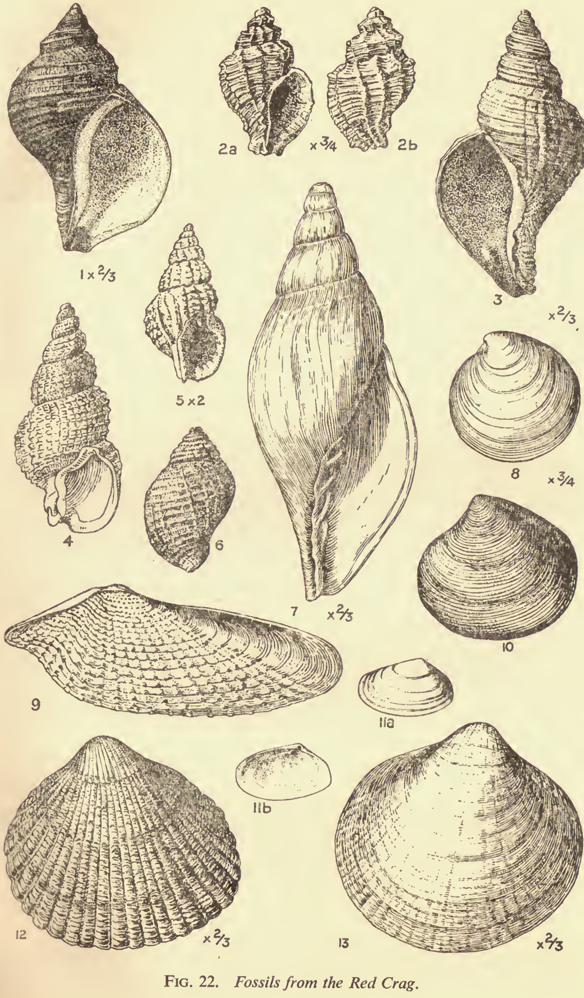

FIG. 22. *Fossils from the Red Crag.*

PLEISTOCENE; RED CRAG

The Red Crag is a shore deposit consisting of current-bedded sands, shelly in places, and with occasional silty bands and layers of ironstone. Its maximum thickness is 40 ft. Shells occur in profusion and bear evidence of having been drifted and deposited in banks, which according to Harmer, were piled near the shores of land-locked bays through the action of prevalent easterly gales. On account of the permeability of the Red Crag beds, certain changes have taken place since their deposition. Among these may be mentioned the staining, which probably resulted from the oxidation of ferrous compounds, and the removal of calcium carbonate by percolating waters. Subsequent deposition of limy material is seen in fissures lined with white carbonate, or in the conversion of the lower beds into white sandy limestone. Over a wide area the Red Crag rests, with a basal detritus-bed, on London Clay. Only in the Stour Valley does it rest on the Chalk.

Three subdivisions of the Red Crag are recognized. Usually subdivisions of strata succeed each other vertically, but as the result of the earth-movements that have been mentioned the shores on which the beds were deposited gradually moved northwards, and so the subdivisions of the Red Crag succeed each other laterally in that direction. The areas they occupy are shown on the map (Fig. 14). Many species of shells range through all three subdivisions, and the following are a selection of those commonly met with.

Waltonian: *Laevicardium parkinsoni*, *Dosinia exoleta*, *Mytilus edulis*, *Spisula arcuata*, *Pholas* (*Barnea*) *cylindrica*, *Aloidis* [*Corbulomya*] *complanata*, *Nassa* (*Hima*) *granulata*, *Neptunea contraria*, *Purpura tetragona*, *Nucella* [*Purpura*] *lapillus*, and *Trochus* (*Calliostoma*) *subexcavatus*.

Newbournian: *Scaphella lamberti*, *Neptunea contraria*, *N. antiqua*, *Capulus ungaricus*, *Tellina obliqua*, *Chlamys* (*Aequipecten*) *opercularis*, *Glycymeris glycymeris*, *Astarte obliquata* and *A. montagui* (=*compressa*).

Butleyan: *Spisula ovalis*, *Cardium angustatum*, *Tellina praetenuis*, *Macoma obliqua*, *Neptunea despecta*, *Euspira catena*, *Boreoscala groenlandica* and *Buccinum groenlandicum*.

In addition to the large number of shells, the Red Crag includes remains of foraminifera, sponges, corals, brachiopods, polyzoa, crinoids, echinoids, and barnacles. Among the flints found in the basal detritus-bed and at higher horizons in the Crag are specimens that have been recognized by some authorities as having been shaped by Early Man (p. 78).

North of Aldeburgh the character of the Crag changes, and the current-bedded, drifted sand-banks of the Red Crag give place to the deposits of a shallow open sea that lay near the estuary of a large northward-flowing river that was probably a forerunner of the Rhine. The deposits that were then formed are called the Icenian Crag (Fig. 14), this term being derived from the name of the Iceni, an ancient tribe of East Anglia. Included in the Icenian Crag are the Norwich Crag, Chillesford Beds, and Weybourne Crag.

THE NORWICH CRAG

This division extends northwards almost continuously from Aldeburgh, in Suffolk, for a distance of about 40 miles; from west to east it extends for nearly

20 miles. It varies considerably in lithic character, and comprises beds of sand, laminated clays, and pebbly gravels. These beds are yellowish or reddish brown in colour and in places are highly fossiliferous. Comparatively thin in the west, they increase in thickness northwards and eastwards, being about 150 ft. at Southwold.

Where the base rests on the Chalk, the surface on which it rests is bored by marine worms and by the bivalved mollusc *Pholas*. A ' Stone-bed ' is also present as a basal layer of the Norwich Crag, resting on the Chalk (Fig. 23). This bed attains a thickness of one foot and consists mostly of brown-coated flints with occasional bones and patches of shells. In this bed also occur the famous flint-implements known as the ' rostro-carinates ' (p. 78 and Fig. 35A). Among the bones in the Stone-bed are those of the mastodon, the dolphin, elephant (two species), antelope, deer, giant beaver, hyaena, and leopard. These

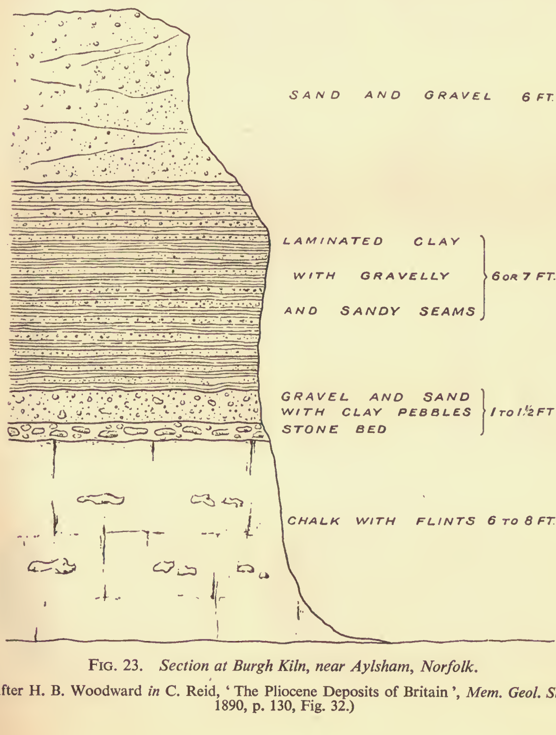

FIG. 23. *Section at Burgh Kiln, near Aylsham, Norfolk.*

(After H. B. Woodward *in* C. Reid, ' The Pliocene Deposits of Britain ', *Mem. Geol. Surv.*, 1890, p. 130, Fig. 32.)

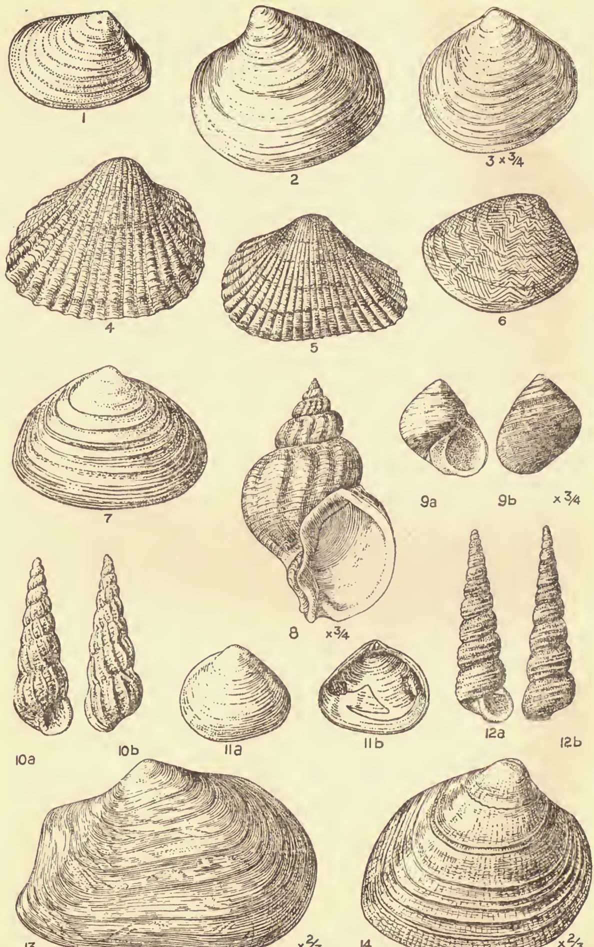

FIG. 24. *Fossils from the Norwich Crag and the Weybourne Crag.*

bones are not phosphatized, and differ in this respect from those in the Suffolk Bone Bed under the Red Crag, in which many were derived from older deposits. The Norwich Stone-bed is, in fact, a marine basement-bed. Bones of mammals have also been found on the Stone-bed and in the overlying deposits.

Shells are common locally in this Crag and show an increase in the percentage of living and northern species. Among the present-day forms that inhabited the Norwich Crag sea were the common cockle (*Cardium edule*), the mussel (*Mytilus edulis*), the whelk (*Buccinum undatum*), and the periwinkle (*Littorina littorea*). Other common shells are *Astarte semisulcata, Cyprina islandica, Phacoides* [*Lucina*] *borealis, Mya arenaria, M. truncata, Nucula* (*Acila*) *cobboldiae, Mactra* (*Spisula*) *ovalis, Macoma* [*Tellina*] *calcarea, Serripes groenlandicus, Boreoscala groenlandica* and *Turritella communis.* Several species of land and freshwater shells occur locally, and were doubtless washed into the estuary, as were some of the bones.

THE CHILLESFORD BEDS

Resting on the Norwich Crag and on the Red Crag at Chillesford (Suffolk) are fine micaceous sands overlain by micaceous clay. These are known as the Chillesford Beds. By linking up the places where the clay occurs, Harmer determined a sinuous outcrop running from Chillesford, through Norfolk, to Burgh and regarded this tract as the course of a former estuary, part of the delta of the ancient Rhine. A slight upheaval in this area is thus indicated. The abundance of mica in the Chillesford Beds certainly suggests a southern origin for this material, probably rocks like mica-schists in the Ardennes. In thickness the beds do not exceed 20 ft., and the marine species found in the sand are as a whole more boreal than those of the Norwich Crag. Among the shells found are *Turritella communis, Yoldia oblongoides, Y. lanceolata, Macoma calcarea* and *Mya truncata.* A complete and undisturbed skeleton of a whale was also found in the clay at Chillesford, and has been regarded as supporting the view that this bed was laid down in a quiet estuary.

THE WEYBOURNE CRAG

A slight depression of the land followed the rise of the area during which the Chillesford Beds were deposited, and brought part of what is now Norfolk once again under the sea and in communication with northern waters. As a result beds of clay, sand and pebbles (the Weybourne Crag) were laid down. These are now exposed in the Norfolk cliffs between Weybourne and Mundesley (Fig. 26).

The fossils of the Weybourne Crag are similar to those of the Norwich Crag, but again the slight increase in northern shells gives evidence of a steady

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FIG. 24. *Fossils from the Norwich Crag and the Weybourne Crag.*

1. *Macoma calcarea* (Chemnitz); 2. *Astarte Semisulcata* (Leach); 3. *Tellina obliqua* J. Sowerby (x¾); 4. *Cardium edule* Linné; 5. *Cardium angustatum* J. Sowerby; 6. *Nucula* (*Acila*) *cobboldiae* J. Sowerby; 7. *Mactra* (*Spisula*) *ovalis* J. Sowerby; 8. *Buccinum undatum* Linné (x¾); 9 a, b. *Littorina littorea* Linné (x¾); 10 a, b. *Scala* (*Boreoscala*) *groenlandica* Chemnitz; 11 a, b. *Macoma balthica* (Linné); 12 a, b. *Turritella communis* Risso; 13. *Mya truncata* Linné (x⅔); 14. *Serripes groenlandicus* Bruguière (x⅔).

FIG. 25. *Fossils from the Cromer Forest-bed Series and other deposits.*

fall of temperature. One notable addition was the small bivalved shell *Macoma balthica*, which arrived in vast numbers in the area at this time. It is the commonest and most distinctive member of the assemblage of shells. Sands that include this shell occur also in the Bure valley and as far south as Norwich; evidently these mark the area of a small inlet. A Stone-bed usually marks the base of the Weybourne Crag: it includes numerous marine shells, and large quartzite pebbles and other boulders have been found between Weybourne and Sheringham.

THE CROMER FOREST-BED SERIES

On account of the large number of mammalian remains that have been found in them, these beds are among the best known in East Anglia. They comprise two beds of freshwater origin, with estuarine deposits (the Forest-bed proper) between, and they occur along the coast between Pakefield and Weybourne, although not continuously, the exposures being interrupted for long stretches where hidden by cliff-falls, and where glacial deposits cut down to the underlying beds. Evidently the Forest-bed was laid down under deltaic conditions, for it contains frequent remains of trees and derived bones and teeth that were washed down by a river.

The Lower Freshwater Bed (2 to 5 ft.) consists of green carbonaceous clay and peaty layers, containing seeds and fruits of plants (Fig. 25, 1-5). It is seldom preserved, and locally its place is taken by a bed of large flints, among which are primitive humanly-fashioned implements.

The Forest-bed, attaining in places a thickness of 20 ft., includes sands and gravel (flints, quartz-pebbles, lumps of clay, etc.), and lenticular beds of laminated clay with seams of sand and gravel. From the manner in which the tree-stumps are embedded in the clay it is evident that they did not grow on the spot: they were swept into their present position. The mammalian remains found in these estuarine deposits include those of elephants, rhinoceros, deer, hyaena, sabre-toothed tiger, bear, beaver and hippopotamus (its first appearance in this country). Shells, among them *Mya truncata*, *Macoma balthica*, and *Cardium edule*, also occur.

The upper surface of the Forest-bed is eroded and weathered, and in places forms a kind of soil which is so traversed by rootlets that it is called the Rootlet-bed. On this eroded and often hollowed surface rests the highly-fossiliferous Upper Freshwater Bed, consisting of 5 to 7 ft. of peaty and loamy sands and carbonaceous clay. Among the fossils in this bed are numerous plant-remains, shells (*Pisidium amnicum*, *Unio tumidus*, *Belgrandia marginata*, *Nematura*

FIG. 25. *Fossils from the Cromer Forest-bed Series and other deposits.*
(1-5 Seeds and Fruit, Upper Freshwater Bed.)

1. *Carex rostrata* Stokes (x3) ; 2. *Potamogeton crispus* Linné (x3) ; 3. *Ranunculus repens* Linné (x6) ; 4. *Rumex maritimus* Linné (x3) ; 5. *Trapa natans* Linné. Fruit (x½) ; 6. *Yoldia* [*Leda*] *myalis* (Couthouy); 7 a, b. *Pisidium amnicum* Müller (a, dentition x2); 8. *Scrobicularia plana* Da Costa; 9. *Unio tumidus* Retzius; 10. *Yoldia* [*Leda*] *oblongoides* (S. V. Wood); 11 a, b. *Corbicula fluminalis* (Müller); 12. *Viviparus gibbus* (Sandberger); 13. *Succinea putris* Linné; 14. *Valvata antiqua* Morris (x2); 15. *Belgrandia marginata* (Michaud) (x6); 16. *Nematura runtoniana* (Sandberger) (x3); 17. Lower jaw of Beaver, *Castor fiber* Linné (=*europaeus* Owen) (x⅔); 18. Molar tooth of *Hippopotamus amphibius* Linné (x⅔); 19. Molar tooth of *Rhinoceros antiquitatis* Blumenbach (x⅔) ; 20. Lower jaw of Vole, *Mimomys* (*Arvicola*) *intermedius* Newton (x2); (b, teeth x3).

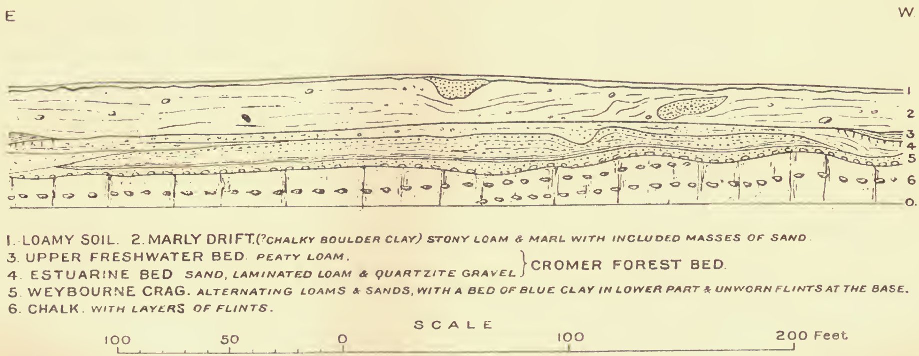


FIG. 26. *Cliff-section about 300 yds. east of the Coastguard Station, Weybourne, Norfolk.* (After C. Reid, 'The Pliocene Deposits of Britain', *Mem. Geol. Surv.*, 1890, p. 141, Fig. 34.)

runtoniana, *Valvata antiqua*, and *Viviparus gibbus*) and bones and teeth of the giant beaver and the vole.

The plant-remains in the Forest-bed indicate a climate that was much the same as that of Norfolk at the present time. The mammalian remains are a mixture of animals associated with warm conditions as well as those indicating a cold climate. Most of the specimens have been obtained through being swept from the deposits by the sea during gales, and this, together with the involved mixture of forms, has led to the suggestion that beds of different ages may be represented. Dr. A. Azzaroli mentions the remains of 15 species of deer from the Forest-bed, with the remark that it cannot be imagined that these lived at the same time. He concludes that the deposit represents several horizons, and recognizes three successive faunas.

THE *Leda myalis* BED

According to Clement Reid and other early workers, the Forest-bed Series was succeeded by the *Leda myalis* Bed, a marine deposit of chalky sand and loam, seen in the Norfolk cliffs near Sheringham. Its fossils are similar to those of the Weybourne Crag with the addition of the bivalved shell now called *Yoldia myalis*. In the view of Dr. Solomon the real position of this bed is above the Arctic Freshwater Bed (p. 62), the earlier views to the contrary being tenable through the possibility of glacial disturbance. Dr. Solomon's researches on the mineral grains in this bed show that the constitution of its upper part indicates the arrival of detritus from the north. The assemblage of mineral grains is that which reached its maximum in the North Sea Drift, the product of the Scandinavian Ice Sheet. Evidently, then, before the *Leda myalis* Bed was completely laid down the first of the great ice-sheets of the Pleistocene period was not far off.

VI. SUPERFICIAL DEPOSITS

INTRODUCTION

THE STRATA THAT have already been described are known as the Solid formations, and the maps that represent them are called Solid maps. Superficial deposits, the latest accumulations, are sometimes referred to as Drift deposits and are represented on different maps called Drift maps. Over most parts of England the Superficial deposits present a marked contrast with the Solid formations over which they were laid down. The latter are of substantial thickness and regular extent, as well as being of considerable age: Superficial deposits are of variable and usually inconsiderable thickness and their extent is irregular; they lie indifferently on older strata and are largely dependent on topography. These distinctions, however, are not maintained over the whole of the district under consideration, for the geographical changes after Pliocene times were gradual and the early Pleistocene beds were comparatively thin; and no great interval of time elapsed before Superficial deposits were spread widely over the area.

The two chief factors in the later Pleistocene history of the district were climatic oscillations, periods of intense cold alternating with intervals of milder climate, and changes in the relative levels of land and sea. The former left their traces mostly in deposits of glacial origin and in the remains of temperate or warmth-loving animals and plants; the latter are evident from the presence of buried channels (Fig. 27), of erosion surfaces now beneath sea-level, of river-deposits arranged as terraces, and of gravels formed during the incursions of the sea.

The dominant episodes of the Pleistocene Period were the successive glaciations, the relics of which are spread over most of East Anglia; we see them now as a mantle of clays, sands, brickearths, and gravels, and to these are mostly due the aspect and agricultural characters of the land. During the Great Ice Age, or Glacial Period, the area was covered more than once by ice-sheets; and as these moved towards and over the area they displaced and transported material from the floor over which they travelled. This material included pieces of hard rocks, often scratched or smoothed in transit, and a matrix of softer material, mostly clay and sand. Some of the hard rocks were brought from as far afield as Scandinavia, but the soft matrix was derived from near at hand. On the melting and retreat of the ice, whether on land or in the sea, the transported material was left in mounds or as continuous sheets. Some of the material was deposited as a heterogeneous and mostly structureless mass now known as Boulder Clay, but active melting gave rise to floods of water which sorted the ice-borne material; sand and gravels were then deposited, while the finest material was laid down as clays, often laminated, in basins of still water beyond the ice-front. In many places movements in the ice-sheet resulted in folding and thrusting of the enclosed material. When the ice evaporated or melted at a slow rate these structures remained after the ice had disappeared; hence originated the term ' Contorted Drift ' for such deposits. Examples of contortions are to be seen at Ipswich (Hadleigh Road, Claydon) (Fig. 28), and in the cliffs near Cromer (Pl. VII B).

Chalk pebbles enter so much into the composition of boulder clay in East Anglia that the term Chalky Boulder Clay has long been in use to denote such

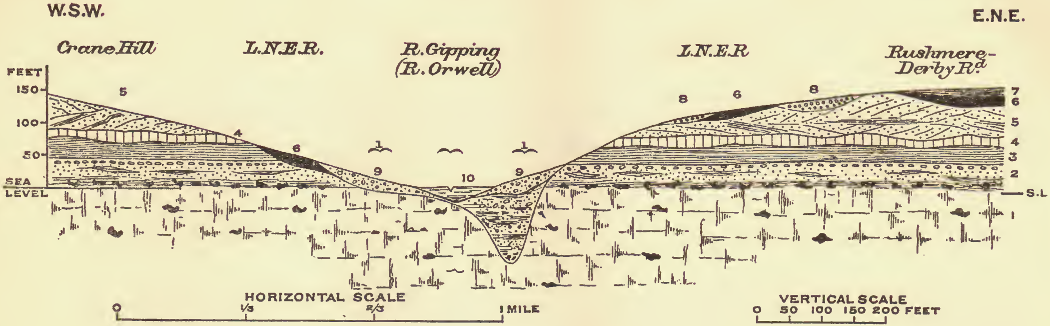


FIG. 27. *General section across the Gipping (Orwell) valley at Ipswich.*
(After P. G. H. Boswell, 'The Geology of Ipswich', *Mem. Geol. Surv.*, 1927, p. 6, Fig. 3.)

1. Upper Chalk. 2. Thanet Beds, etc. at base, Reading Beds and Oldhaven (?) Pebble Beds. 3. London Clay. 4. Red Crag. 5. Glacial Sand and Gravel. 6. Boulder Clay. 7. Loam and Brickearths (post-Boulder Clay). 8. Morainic gravels. 9. River Terrace (sand and gravel). 10. Alluvium.

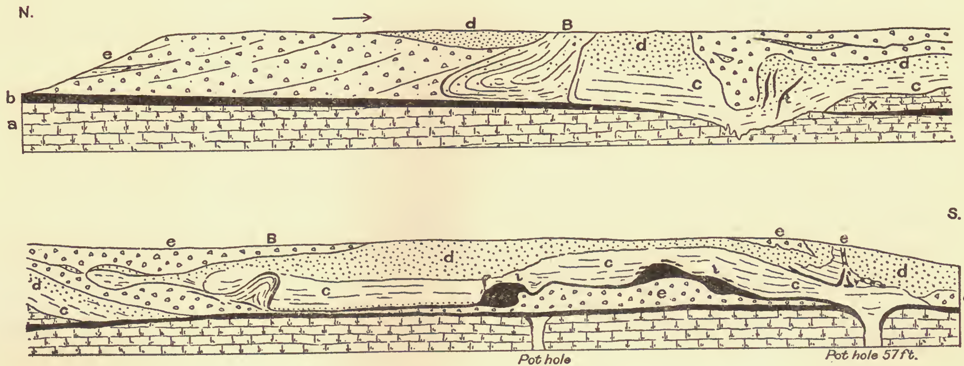


FIG. 28. *Section at Claydon Chalk Pit, near Ipswich.*

(After G. Slater *in* P. G. H. Boswell, 'The Geology of Ipswich', *Mem. Geol. Surv.*, 1927, p. 53, Fig. 12.)

a. Chalk. x. A chalk boulder, 42 ft. long. b. Thanet Beds. c. Decalcified Crag. d. Sands and Gravel. e. Boulder Clay, buttressed against decalcified Crag at B and B.

material. Certain varieties have been distinguished such as Chalky Jurassic, Chalky Kimmeridgian and Chalky Neocomian, but these names refer to lithological character and not relative age, and since in a few localities one boulder clay has been seen above another, it is necessary to distinguish between them in order to form a clear picture of the glacial history of the area. The nature of the matrix and the contained pebbles are used for this purpose, and from a study of the constitution of the boulder clays Mr. Baden-Powell has recognized the deposits and so suggested the direction of movement of the second and third ice-sheets in East Anglia (Fig. 31 B and C).

At least four glacial stages appear to be represented in the area, and the names of the successive ice-sheets as used by Dr. J. D. Solomon in describing their deposits on the north Norfolk coast are 1, North Sea; 2, Great Eastern; 3, Little Eastern; 4, Hunstanton. The boulder clay of the second (Great Eastern) glaciation, sometimes called the Great Chalky Boulder Clay, is also known as the Lower Chalky Boulder Clay, or as the Lowestoft Boulder Clay because it is typically developed there. The boulder clay of the third (Little Eastern) glaciation has also been called the Upper Chalky Boulder Clay, the Upper Chalky Drift or the Gipping Boulder Clay because it was first recognized in the Gipping Valley.

The ice-sheets that gave rise to these two chalky boulder clays differed somewhat in direction of movement and the boulder clays are correspondingly different in matrix and in their contained erratics. Two main types of boulder clay are recognizable: a dark type consisting of a matrix of sand and Jurassic clay, and a pale type with a sandy chalky matrix. The erratics of the Lower Boulder Clay include, besides chalk, flint and Jurassic rocks, Neocomian sandstone, Bunter quartzites and dark-blue limestone. Movement south-eastwards from the Pennines is therefore suggested. The Upper Chalky Boulder Clay contains more chalk than the Lower and is paler in colour. Among the erratics are chalk, flint (some with blue and white ' basket-work ' patina), abundant pebbles of Red Chalk and bits of porphyrite of a Scottish Old Red Sandstone type. It is evidently the product of Scottish ice, coming from a northerly direction off the present Lincolnshire coast. Thus, in the Lowestoft stage a chalky-Jurassic boulder clay was being formed at Lowestoft and Ipswich at the same time as chalky boulder clay at Cromer; and at the Gipping stage a chalky boulder clay was formed at Ipswich contemporaneously with chalky-Jurassic boulder clay in the Fenland (Fig. 31 B and C).

In addition to the small boulders and fine-grained soft material which constitute the bulk of the boulder clay, huge masses of rock are included here and there (Pl. VII A). Several great masses of chalk, one over 600 yds. in length, are to be seen in the glacial deposits in the cliffs on the northern coast of Norfolk; at Biggleswade a transported mass of Ampthill Clay (67 ft. in thickness) has been found also embedded in Boulder Clay; while at the Roslyn Pit, near Ely, is a mass of Chalk, Greensand and Gault, 450 yds. in length and 60 yds. in width, that was moved from its original place and dumped into a hollow in the Kimmeridge Clay. Disturbances due to glacial action are also to be noted in the Chalk itself; at Trimingham it was bent in the form of a loop, while at Trowse, near Norwich, the Chalk was seen to be uptilted to about 35 degrees, with Drift deposits beneath it.

Deposits on the Norfolk Coast

The succession of Superficial Deposits is most complete in Norfolk, and that area, particularly the northern coast, is the most suitable as a starting place in the consideration of this succession. As the first of the Superficial deposits in this area, we may note the Arctic Freshwater Bed, which consists of laminated peaty loams (1-4 ft.), and contains plant-remains (among them fragments of Arctic Willow and Arctic Birch) and freshwater shells (*Succinea putris, Valvata piscinalis*, etc). It is rarely exposed but has been seen on the coast at Mundesley, Beeston, and near Bacton; in the opinion of Clement Reid it was a once continuous and important horizon. The decidedly arctic character of this bed places it with the main glacial deposits of the area. These occupy most of the surface of East Anglia, and there is evidence of a period of less intense cold, or an interglacial phase, after each of the successive stages.

THE NORTH SEA DRIFT

The deposits of this Drift evidently originated from an ice-sheet which came from a direction slightly east of north, and which presumably melted in water. These assumptions are based on the facts that the movement of this sheet did not disturb the underlying deposits, that the various members are homogeneous (excepting the pebbles), and that the Eocene materials are included among its constituents; the last-mentioned giving a clue to direction. Four divisions are recognized: a Lower Till, the Mundesley Sands, an Upper Till, and a deposit of sands and clays. The Tills are tough, grey, sandy boulder clays, containing as erratics much chalk, flint, schist, gneiss, and igneous rocks from Scandinavia and Scotland; material from Jurassic formations, and septaria derived probably from Eocene deposits are also included. The two Tills can only be distinguished when separated by the Mundesley Sands (greyish silty sands, 45 ft. at Mundesley); in some places where apparently one Till is seen probably two are present. The Upper Till has the appearance of stratification, and contains fewer erratics and less chalk than the Lower Till. The next layer to be formed was a thickness (up to 10 ft. between Trimingham and Overstrand) of sands with occasional beds of clay. In mineral constitution this layer is evidently related to the underlying Till, and it contains marine shells which show that it is a continuation of the ‘ Middle Glacial ’ sands (the Corton Beds) of Corton, near Lowestoft. Resting evenly on either the sands and clays or the Upper Till are the Laminated Clays (the ‘ Intermediate Beds ’ of Reid), grey in colour, but often yellow and chalky at the top, and attaining a thickness of 20 ft.

GREAT EASTERN DRIFT

Considerable erosion evidently preceded the arrival of the Great Eastern ice-sheet, because certain deposits of the earlier glaciation have been removed in some places, while farther south the products of the second ice-sheet lie in valleys cut in the North Sea Drift. The Great Eastern ice-sheet was also instrumental in the contortion of older drifts on the north Norfolk coast, and their moulding into drumlin-like forms. The principal deposit of this ice-sheet was the Lower Chalky Boulder Clay, or Marly Drift, which, west of Cromer, was clearly a product of land-ice. Pebbles of chalk, flint quartz and quartzite, as also broken shells, are common in this boulder clay, but the few far-travelled erratics that it contains were probably derived from earlier glacial deposits, which it incorporates in some quantity. The ice-sheet that produced this boulder clay approached from a direction west of north.

Above this boulder clay in various places is a series of sands and gravels, which is also evidently outwash-material deposited near the edge of an ice-sheet. Near Happisburgh the deposit consists of fine sands, chalky near the base; north-westward it becomes increasinly coarser until at the western end of the coast-section it is a coarse gravel. In some places this Chalky Outwash Sand and Gravel rests on eroded surfaces.

During the interglacial period that followed the Great Eastern glaciation active erosion was in progress; at Bacton and West Runton the Lower Chalky Boulder Clay and overlying outwash-deposits were removed, and shallow valleys became occupied by sands and gravels composed to a large extent of materials derived from them. This interglacial deposit is known as the Bacton Valley Gravel. At the north-western end of one exposure of this gravel are small contortions which were evidently produced during the advance of the next ice-sheet.

LITTLE EASTERN DRIFT

The third ice-advance is represented on and near the north Norfolk coast by two divisions: Sandy Brickearths, etc., and part of the Cromer Ridge Gravels. The Sandy Brickearths include brownish loams and brickearths which occupy basins near the top of the cliffs; in places they rest on contorted beds. The Upper Gravel of Cromer Ridge (the Blakeney Gravel of Baden-Powell and Reid Moir), an unsorted gravel mostly of rounded flints, grey inside, some with the ' basket-work ' type of patina, forms a veneer on the top and sides of the Ridge and spreads westwards towards Holt and Blakeney as a cannon-shot gravel. The earlier Lower Ridge Gravel (the Briton's Lane Gravel) a well-bedded deposit of at least 70 ft., is probably associated with the Great Eastern Drift.

HUNSTANTON BOULDER CLAY

The fourth ice-advance gave rise to a reddish-brown boulder clay, found at Hunstanton and other places on the northern coast of Norfolk. There is a large exposure of the boulder clay in the brickfield in Holkham Park. The erratics are different from those of previous glaciations; they include grits and igneous rocks similar to those found in the Cheviot Hills, but practically no chalk, an assemblage that is typical of the Hessle Boulder Clay of Yorkshire and Lincolnshire. The fragmentary minerals found in the clayey matrix furnish confirmatory evidence of the source of the deposits, and afford a ready means of distinguishing them from the products of earlier glaciations. That this fourth boulder clay was formed at a later period is shown by the fact that at Morston it overlies an ancient low-lying shingle-beach which contains much pale grey flint obviously derived from the Upper Ridge Gravel. The ice-sheet does not seem to have surmounted the Cromer Ridge in strength, though the clay has been found above 60 ft. O.D. south of Stiffkey.

The deposits just described are nearly all exposed in the cliffs of Norfolk between Hunstanton and Happisburgh. As will be gathered from the descriptions, the members exposed vary from place to place on account of restricted distribution or subsequent erosion. A typical cliff section is that near Happisburgh (Fig. 29); while the most complete succession of the drifts of the North Sea and Great Eastern ice-sheets is to be seen west of the chalk bluffs at Trimingham. Here the following beds were determined by Dr. Solomon:—

Great Eastern Drift	Chalky Outwash Sands and Gravels	20-30 ft. to top of cliff.
	Chalky Boulder Clay	to 10 ft.
	Gravelly and chalky yellow sand	to 12 ft.
	Laminated stoneless and chalky clay	to 20 ft.
North Sea Drift	Clean yellow sands	10 ft.
	Upper Till	40 ft.
	Mundesley Sands	15 ft.
	Lower Till	10 ft. to beach.

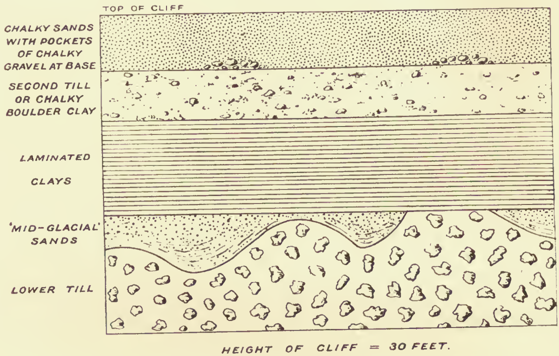


FIG. 29. *Section north-west of Happisburgh Gap, Norfolk.*

(After J. D. Solomon, *Proc. Geol. Assoc.*, vol. xliii, 1932, p. 252, Fig. 22.)

INLAND DRIFT DEPOSITS

The succession of glacial beds on the northern coast of Norfolk provides useful terms of reference in the consideration of similar deposits in other parts of the area. In South Norfolk the sands associated with the North Sea Drift are represented by the Westleton Beds, consisting of pebbly or sandy gravel, which extend as a broad belt from near Mundesley to Dunwich and Westleton and were formed as shingle or sands on the shore of an encroaching sea. This was the sea that lay in front of the first advancing ice-sheet. Overlying these gravels in places are beds of boulder clay, often decalcified and weathered and known as the Norwich Brickearth. This boulder clay is the product of the first glaciation, and is the equivalent inland of the Till; it is characterized by its erratics, mostly pieces of flint and of Scandinavian rocks. Corresponding with the sands and clays that follow the Upper Till on the coast, are current-bedded sands and gravels—the Mid-Glacial Sands and Gravels of earlier workers. These were so named because in some places they are overlain by a later boulder clay. They are exposed to the north and east of Norwich, where they form sandy heaths; and at certain localities between Yarmouth and Norwich the sands contain quantities of marine shells. Mr. D. F. W. Baden-Powell and Reid Moir recently adopted the name Corton Beds for this marine horizon.

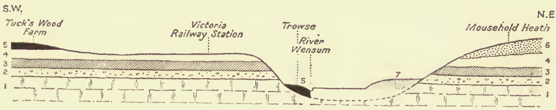


FIG. 30. *Section across the valley of the Wensum at Norwich showing the Chalky Boulder Clay as a valley-deposit.*

(After F. W. Harmer, ' Geology in the Field ', *Geol. Assoc.*, 1909, p. 120, Fig. 25.)

1. Chalk. 2. Crag sands and pebble-beds. 3. Norwich Brickearth. 4. 'Mid-Glacial' sand. 5. Chalky Boulder Clay. 6. Cannon-shot gravels. 7. Valley gravel.

The second ice-advance gave rise to the Lower Chalky Boulder Clay, which has a wide extent in the area. Over the greater part of north and central Norfolk its matrix is chalky and sandy; in the area to the south the matrix is dark and of a Jurassic type, consisting of a mixture of sands and clays. The junction of the two types can be seen at Bawsey, east of King's Lynn, and Scratby, north of Yarmouth. The Lower Chalky Boulder Clay can be seen resting on the Corton Beds at Corton and south of Pakefield.

The Upper Chalky Boulder Clay is exposed at several pits near Ipswich; its matrix is a mixture of chalk and sand, with some pale brown clay. A pale boulder clay of the Gipping type is common in north-west Suffolk and West Norfolk. Mr. Baden-Powell records it from around Mildenhall, from south-west of Thetford and from various places between Thetford and Diss. It is seen in weathered form at Hoxne brickyard; but apparently its place east of a line from Quidenham by Hoxne to Ipswich is taken by cannon-shot-like gravels.

As a geological deposit chalky boulder clay presents a flat surface over wide areas and varies considerably in thickness, being thickest as a rule over the higher parts of the plateau between the main streams. Over such parts measurements from 100 to 150 ft. have been commonly recorded, while thicknesses of between 150 and 230 ft. are known on the higher ground between Bury St. Edmunds, Haverhill, Clare, Lavenham and Stowmarket. Associated with chalky boulder clay as outwash-material are some of the cannon-shot gravels, which occupy high ground in Norfolk and Suffolk.

During the decay of the Great Eastern ice-sheet great torrents flowed out from beneath it and scoured out deep channels, which were subsequently filled with glacial drift. These channels are of considerable length, have steep sides and uneven floors, and may be as much as one-quarter to one-half a mile in width. In general their course is much the same as the longer present streams but some have been located on the plateau, as at Shropham, about 11 miles north-east of Thetford. The nature of the infilling varies, being boulder clay, sand, gravel or silt. There is no indication of the presence of buried channels at the surface, and our knowledge of them has been obtained from the evidence of borings and may therefore be extended by further exploration. The following are the principal channels found in our area: (1) a single channel in the valleys of the Upper Cam and Stort, extending from Whittlesford southwards through Ickleton and Great Chesterford; (2) in the Stour Valley from Thurlow to Kedington and presumably following the course of the river through Cavendish and Glemsford towards Sudbury : the deepest channel in East Anglia–347 ft. O.D. at Glemsford and–286 ft. O.D. at Cavendish ; (3) in the Brett valley

FIG. 31. A. *Distribution of Chalky Boulder Clay, Eastern England.*
(After S. V. Wood, jun., *Quart. Journ. Geol. Soc.*, vol. xxxvi, 1880, pl. xx).

B. *Direction of Ice-movement during the Lowestoft (Lower Chalky) Glaciation.*
(After D. F. W. Baden-Powell, *Geol. Mag.*, 1948, p. 284).

C. *Direction of Ice-movement during the Gipping (Upper Chalky) Glaciation.*
(After D. F. W. Baden-Powell, *Geol. Mag.*, 1948, p. 285).

extending possibly from Lavenham, through Chelsworth to Hadleigh; (4) in the Gipping Valley from Stowmarket to Ipswich; (5) in the valley of the Lark from West Stow, through Culford and Bury St. Edmunds, with tributaries running north-eastwards; (6) in the valley from Ixworth to Euston, then possibly connecting with a channel in the Little Ouse Valley; (7) in the valley of the Waveney at Blo-Norton and Stuston.

Occupying large areas east and south-east of Ipswich are sands and shingly gravels (formerly termed Mid-Glacial) which gave rise to the well-known heathlands (Pl. IV A). From the evidence of their mineralogical constitution Dr. Solomon regarded them as part of the Westleton Series, of early glacial age. Towards the north-west the sands and gravels are overlain by chalky-Jurassic boulder clay, containing in this part of the country a great variety of erratics from the Old Red Sandstone (Scottish) and later rocks. Lake-like hollows in the surface of the sands were filled with laminated clays laid down in water from the advancing ice (Fig. 34) which contorted them. Similar hollows in the surface of the boulder clay were filled on the retreat of the ice, as seen in the section at Derby Road, Ipswich. At this locality the laminated clays are capped by contorted ferruginous flint gravels, containing wisps of boulder clay and brickearth and resembling some of the cannon-shot gravels of Norfolk, probably due to the Upper Chalky glaciation. At other localities these uppermost gravels rest on chalky boulder clay or even on the Westleton Beds.

Striking examples of disturbed deposits referred to above as ' fossil glaciers ' were to be seen in the Hadleigh Road area at Ipswich, and one series is still to be seen at Bolton and Co's. (Dales Road) brickyard north-west of that town, where the London Clay is channelled and contorted.

Interglacial deposits between the Lower and Upper Chalky Boulder Clay were to be seen at the famous locality of Hoxne (Figs. 32 and 33). Here the following succession was determined by Clement Reid (see also p. 86):—

	Ft.	In.
Surface soil	to 1	0
Sand and sandy loam	3	0
Glacial deposit (Upper Chalky Drift) (mixture of clay, gravel, and sand, with chalk pebbles)	6	0
Brickearth, with a 1 ft. band of peat at the base, with temperate plants and mollusca	8	0
Gravel, with bones of mammoth, reindeer, etc.	4	0
Lake-bed, with arctic-birch, arctic willow, etc.	20	0
Peat, with abundant mosses and plants	3	0
Lake-bed, with temperate plants and molluscs	20	0
Chalky-Jurassic (Lower Chalky) Boulder Clay	24	0
Glacial sand		

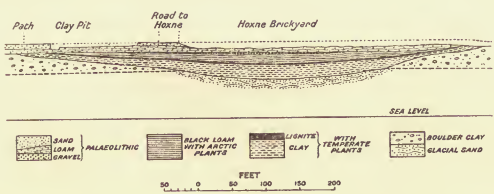


FIG. 32. *Section through Hoxne Brickyard, Suffolk.*

(Adapted from the Report of the Committee to investigate the Relation of Palaeolithic Man to the Glacial Epoch, *Rep. Brit. Assoc.*, for 1896, pl. facing p. 401.)

Excavations in a gravel pit by the Suffolk-Essex border at Brundon, near Sudbury, carried out from 1935-1937, have developed an important exposure of glacial and interglacial deposits with associated fossils and flint implements. The lower beds include a boulder clay which was probably produced by the Upper Chalky Boulder Clay glaciation, and the upper glacial bed, or beds, probably represents the Brown Boulder Clay of Hunstanton. Between them are traces of a land-surface with unworn and unpatinated flint implements and flakes associated with a rich assemblage of mammalian remains and non-marine shells. The unworn implements are of the Lavallois type, and the mammalian remains include bones and teeth of the wolf (*Canis lupus*), cave bear (*Ursus spelaeus*), horse (*Equus caballus*), lion (*Panthera leo*), rhinoceros (*Rhinoceros sp.*), red deer (*Cervus elaphus*), Irish deer (*Megaceros hibernicus*), bison (*Bison priscus*), fossil ox (*Bos primigenius*), straight-tusked elephant (*Elephas antiquus*) and mammoth (*Elephas primigenius*). There were 30 species of non-marine shells, 13 freshwater and 17 land species, the mixture evidently being the result of a flood; and the evidence of the shells, including that of *Belgrandia marginata*, indicates that the climate of the time of the river deposits was warmer than that of today. The animal remains represent a fauna which lived on open grassy plains, with wooded areas not far away. The land surface is at the base of a river-gravel of the ancient Stour, which has yielded artefacts of various ages and types, including early Clactonian, early and late Acheulian and Lavallois. A silty layer with *Corbicula* occurs near the base of the gravels.

The history of the later glaciation of Cambridgeshire is not easily deciphered and further work remains to be done before definite conclusions can be established. There are, however, certain indications that this region was affected by glacial conditions subsequently to the formation of the Chalky Boulder Clay. Among the evidences of these later glacial phases are the puckering of terraced river gravels, evidently caused either by the over-riding action of ice, or by solifluxion, in the Granta valley at Stapleford and Shelford (Pl. V B). Also, at the former locality, a loamy deposit overlying the disturbed gravels may be a boulder clay, like the clayey material found above gravels in the Traveller's Rest Pit, near Cambridge. An interesting feature was formerly visible near Whittlesey, in the Fenland, where a crevasse in late glacial gravels was observed to be sealed in by a loess-like loam. Such crevasses, formed by ground-ice wedges, are associated with tundra-conditions.

The latest glacial deposits in this part of the country are grouped as the 'Late Glacial Drift', and comprise detached masses of gravel, sand, and loam, mostly situated on ridges and spread indifferently on Boulder Clay or Chalk. For the most part they are deeply weathered, disturbed, and sometimes iron-stained. The weathering, however, is characteristic of the upper part; beneath is stratified and current-bedded gravel with bands of sand and loam, evidently arranged by running water. The deposits contain much broken-up chalk and an abundance of erratics, the commonest being those found also in the Chalky Boulder Clay, from which most of the material of this Drift has doubtless been derived. Among the erratics also are pieces of rock from Scandinavia and Scotland, the presence of which suggests their secondary derivation from the North Sea Drift.

A glacial origin is likewise thought probable for the chain of gravel spreads that extends from Furze Hill, Hildersham to the Gog Magog Hills. These spreads, formerly classed as Plateau Drift, which are characterized in particular by flat tops, are now thought to form a small esker-chain (Pl. III A). Several other spreads of gravel, differing in constitution and arrangement from those below the Chalky Boulder Clay, and at one time thought to belong to an 'Ancient River System', are now regarded as of glacial origin. These occur at heights up to 270 ft. O.D. at Whittlesford, and near Balsham, and at other places.

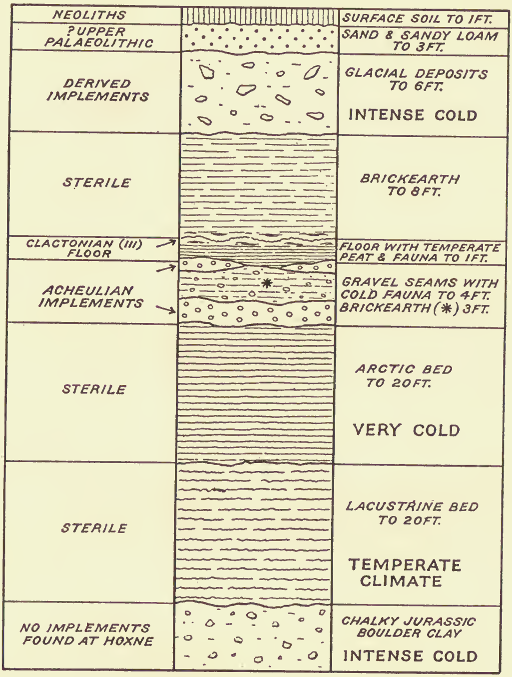


FIG. 33. *Composite section of the beds at Hoxne showing the various climatic changes and horizons at which the flint implements occur.*
Not drawn to scale.

(After J. Reid Moir, *Proc. Prehist. Soc. E. Anglia*, vol. iv., pt. 2, 1926, p. 152, Fig. 2.)

The Superficial Deposits of the Cam valley system, which have received special attention, are interesting because of their abundant fossils and because they supplement our knowledge of the Pleistocene history of East Anglia. The history of the deposits is complex, however, largely because subsidence of the area caused a filling up of the valleys (aggradation) and was followed by periods of erosion, with minor aggradations, during which the present system of rivers was being developed, in many places only a short distance from their former courses. In places, layers of gravel, left on a single terrace, are of different ages; in such cases, therefore, height above sea-level is not a criterion of relative age.

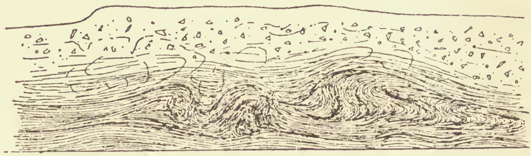


FIG. 34. *Brickearth and Boulder Clay, Hasketon Brickyard, Suffolk.*
(After P. G. H. Boswell, 'The Geology of Ipswich', *Mem. Geol. Surv.*, 1927, p. 57, Fig. 16.)

3. Chalky-Kimmeridgic Boulder Clay, passing irregularly down into buff loam. 2. Buff loam, very much disturbed. 1. Blue laminated loam, contorted.
Section about 10 ft. in height.

The following is the apparent succession of the beds, the oldest being at the bottom of the table:

Barnwell Station Beds
Upper Barnwell Village Beds
Upper (evenly-bedded) gravels of Traveller's Rest Pit
Unevenly-bedded gravels of the Traveller's Rest Pit
Lower (evenly-bedded) beds of Traveller's Rest Pit; Lower Barnwell Village Beds; Barrington Gravels

The Barrington Gravels are gravelly silts that occur in hollows in the surface of the Chalk Marl in the Rhee Valley at Barrington. These deposits, the material of which was largely derived from the Boulder Clay, are notable because of the abundance of remains of hippopotamus and other large mammals; shells such as *Corbicula ouminalis*, sometimes referred to as *Corbicula consobrina*, are also included. Boulders, several bearing marks of scratching by ice, also occur in this gravel, among them some of Scandinavian origin, some of Millstone Grit, and some that came probably from the Cheviot Hills; but there is a notable deficiency in Jurassic rocks. It should be mentioned that the mammals, *Corbicula* and the boulders occur at the base of the deposit, while the beds above are shown by their contained shells to be much newer in age.

An assemblage of mammals similar to those of the Barrington Gravels is found in the Lower Barnwell Village Beds. These beds occur on the highest terrace (25 to 40 ft. O.D.) of the Cam near Cambridge and consist of gravel, sands and loams; they were probably formed on an extensive alluvial tract. In association with remains of hippopotamus several shells have been found, among them being *Unio littoralis*, *Belgrandia marginata*, and *Corbicula fluminalis*. These come from the lower part of the gravels; bones of several species of large mammals (the mammoth, woolly rhinoceros, Irish deer, cave-lion, cave-hyaena, etc.) have been collected, but probably these all come from a higher horizon (see p. 71).

The gravels of the Traveller's Rest Pit are part of a series that occupies a ridge between the Cam valley and a minor valley on the west. They reach a height of 88 ft. above O.D near the Traveller's Rest Inn, north-west of Cambridge, and 84 ft. above O.D. at Cambridge Observatory; and are sometimes referred to as the Observatory Gravels. Three principal divisions can be detected in these gravels: (1) lower evenly-bedded deposits, gravels, sands, and loams, with big boulders near the base; (2) unevenly-bedded gravels, of materials similar to (1) but irregularly stratified; many boulders at the base; (3) deposits of brown sandy loam with scattered flint pebbles, filling erosion channels; also (4) upper evenly-bedded deposits similar to those below but thinner. The whole series has been exposed to a thickness of 18 ft. Fossils are rare in these deposits, but from the occurrence of flint implements (see p. 84) it seems likely that Acheulian types belong to the lower evenly-bedded series, and ' Mousterian ' (probably early Levallois) forms to the unevenly bedded series above. The latter probably marks the oncoming of the Little Eastern glaciation. A break of appreciable importance is indicated by the junction between unevenly-bedded gravels and the upper evenly-bedded deposits. The gravels of the Traveller's Rest Pit provide evidence of considerable aggradation, since they yield implements of ' Mousterian ' type at a level 40 ft. above the Barnwell gravels with *Corbicula* and *Hippopotamus*, although they are newer in age. The tributary valley and the main valley in which they were respectively deposited were doubtless joined not far below Cambridge.

The Lower Barnwell Village Beds at Barnwell and other localities, shown by their flint implements to be of Acheulian age, are overlain non-sequentially by gravels—the Upper Barnwell Village Beds—that yield numerous remains of mammals (deer, woolly rhinoceros and mammoth) but no shells. In these upper gravels, humanly-fashioned implements, a bone cut by Early Man, and a 'pot-boiler' have been found; the evidence of this human activity points to these beds as being of late Palaeolithic age. After the formation of the Upper Barnwell Village Beds a spread of gravel formed what is known as the Intermediate Terrace.

The Barnwell Station Beds were apparently deposited in a channel now partly buried beneath the alluvium of the River Cam. They consist of gravel and clayey and sandy loams containing remains of plants (arctic willow, dwarf birch, etc.), insects, shells, including *Columella columella*, and bones of reindeer. All these indicate an arctic climate, and the deposit evidently the latest cold episode in our area, comparable with the fourth glaciation.

We have seen that a period of aggradation followed the warm episode during which *Hippopotamus* was living in the area. This coincided with depression of the land and a consequent transgression of the sea into the area of the present Fenland. The sea, which occupied probably the whole of the Fenland, is referred to as the March—Nar sea because it left behind it beds of gravel at March and clays in the Nar Valley. Mr. D. F. W. Baden-Powell, who has made a detailed study of the March gravels, considers that marine fossiliferous gravel at Hunstanton was formed at the same time as the March gravels and the

Nar Valley clays, and estimates that the general average submergence in the Fenland was about 40 feet.

The March gravels include sands and gravel which contain remains of marine organisms (foraminifera, ostracods, echinoids, and shells), and which occur on the ' islands ' in the Fenland. Most probably these gravels were formed on sandbanks, which would have been dry at low tide. Where the beds are best developed the general sequence is sand and gravel (12 ft.) succeeded by brickearth (6 ft.), the sand and gravel containing well-rounded pebbles, false-bedded on a large scale, with abundant marine shells including *Mytilus edulis*, *Macoma balthica*, *Cardium edule*, *Turritella communis*. *Corbicula fluminalis* also occurs. The marine shells indicate a climate rather colder than the present day, and comparable with that of southern Norway and Denmark.

The relationship of the March gravels to the Chalky-Jurassic Boulder Clay (most probably of Gipping age) cannot be seen at the present time, but the gravels include large quantities of Jurassic fossils and erratics, which were evidently derived from the boulder clay. Above the gravels is a deposit of brickearth, presumably representing the Brown Boulder Clay of Hunstanton.

Recent species of marine shells are also found in the Nar Valley clays and in the sand and gravel (the Hunstanton gravel) at Hunstanton.

A sequence of Pleistocene deposits, with associated Palaeolithic industries, has recently been determined in the Breckland area, by Dr. T. T. Paterson. This sequence amplifies the succession at Hoxne (p. 67) and confirms our speculations of the evidence of the Little Eastern Glacier (Upper Chalky Drift) there. There are three boulder clays in the Breckland: a Lower, characterized by erratics from northern areas as well as Jurassic material, and a Middle and an Upper, much alike and containing a large quantity of Triassic and other English material, but none from any great distances. The Lower (equated with the Norwich Brickearth) is found only on the slopes of ancient valleys and on higher ground. Its deposition was followed by uplift, extensive erosion, aggradation and a warm climate, then a further period of aggradation with a temperate climate, after which came the advance of an English glacier, depression of the land some 150 ft., and the formation of the Middle Boulder Clay (equated with the Great Chalky Boulder Clay, the Great Eastern Drift). The second (and shorter) interglacial episode repeated the sequence of the first, with two temperate phases and a colder oscillation between them. Following slight erosion the Upper Boulder Clay was formed. This is equated with the Upper Chalky Boulder Clay and Little Eastern Drift, and was deposited as a thin skin over most of the Breckland, though not in the hills to the south. Erosion, dissecting the Upper Boulder Clay and its associated gravels, which formed an Upper Terrace, cut the present radial drainage of the Breckland; a Middle Terrace of well-bedded gravels was formed, with evidence of a cold fauna and then sludging in the upper part; and a late Low Terrace was laid down after erosion and aggradation.

Acheulian and Clacton industries have been found in these deposits. Lower Acheulian and Lower Clacton occur in the early part of the lower-middle interglacial beds, Middle Acheulian and Middle Clacton during the later part of the lower-middle interglacial, and Upper Acheulian and Upper Clacton in the middle-upper interglacial. A Final Acheulian industry appears in the post-Upper Boulder Clay aggradation gravels.

HIGH-LEVEL GRAVELS

Scattered on the lower part of the Chalk escarpment in Cambridgeshire at levels varying from 190 to 90 ft. above O.D. are spreads of gravel which form undulating ridges and little plateaux. These gravels were obviously laid down by water and were once assigned to the 'Ancient River System.' They are now regarded by Mr. Osborne White as remnants of widespread fans of material brought from higher levels of Chalk and Boulder Clay and strewn by heavy torrents. In constitution they are similar to the glacial drifts, with a large proportion of Chalk in pieces of various sizes: their structure is lenticular and shows current-bedding, with occasional seams of evenly-bedded sand and loam. It is thought that these gravels originated through the annual melting of the upper few feet of ground that was frozen to some depth and the consequent solifluxion of the superficial deposits. The transportation of the sludge was in some cases aided by melting snow. The name ' Taele ' (denoting deeply-frozen ground in Norway and Denmark) has consequently been applied to these gravels.

CLAY-WITH-FLINTS

Capping the higher ground of the Chalk in Bedfordshire are accumulations of reddish or chocolate-coloured clay, in which are unworn flints, rounded pebbles and quantities of sand from Eocene deposits (Reading Beds). Part of this is the product of long-continued erosion of the Chalk in situ and part was derived from the destruction of Eocene deposits. The mixing-up of the material may have been due to local glacial action. Doubtless the Clay-with-flints formerly extended over most of the Chalk surface in this area, but this has since been dissected by dry valleys. In thickness the deposit varies from a few feet to 30 ft. or more; and it rests on an irregular surface of the Chalk, sometimes in hollows.

FEN DEPOSITS

The whole of northern Cambridgeshire and parts of Norfolk, Suffolk, Northamptonshire and Lincolnshire are occupied by Fenland (Pl. VIII B). The area is a flat expanse of peat, estuarine silt and clay, deposited under changing conditions after the Ice Age.

Diverse views have been held as to the stratigraphical significance of these beds: on the one hand the fen clay, for example, was held to be of no stratigraphical value, while at the other extreme the sequence of the deposits was held to be constant. As a result of investigations carried out by the Fenland Research Committee a different picture is presented. The peat has been examined by botanists with particular reference to the pollen content of the successive layers, which reflect changes in the forests; the silts and clay have been examined from the point of view of their content of foraminifera and diatoms; while the help of archaeology was enlisted whenever material was available. Systematic boring and excavation gave access to beds beneath the surface.

In such an area as the Fenland the formation of the peat was evidently affected by the relative movements of land and sea. The seaward deposits would tend to be silts and clays, while peat would be formed landwards. Submergence of the land would cause silts and clays to be deposited transgressively over previously formed peat; while emergence during an upward movement would result in peat extending seawards over the silts and clays. As a result there would be an alternate wedging out of silts and clays on one side and of peats on the other. On the landward margin there would be only one peat bed, seawards there are two peat beds, separated and overlaid by silt and clay, and dividing seawards in places into minor peat beds.

With the recognition of these principles in the conditions of deposition of the fen beds, it is obvious that the junction of the peat and the clay at any place marks the time at which freshwater conditions changed to estuarine, or vice versa; it is not a synchronous horizon. The sequence of these deposits and their varied character mark the variations in climate and vegetation, and the transgression and regression of the sea. In the southern Fenland this complex history has been interpreted as a series of well-marked phases, which are recognizable throughout the area. These phases, as determined by Drs. H. Godwin and M. H. Clifford are: (1) the beginning of peat formation; (2) the lower peat stage; (3) the fen clay and silt stage; (3a) the end of the fen-clay stage; (4) the freshwater phase of the upper peat; (5) the *Sphagnum*-peat phase of the upper peat; (6) the phase of the formation of the meres.

The main beds are traceable from the fen margin to Wisbech, but the fen clay does not extend quite to the margin. The lower peat merges into the upper peat at the fen margin, and both the lower peat and the fen clay are thick and continuous deposits.

Fen clay and silt contain foraminifera and diatoms, which are reliable indexes to the degrees of salinity of the water, and the content of these organisms as shown by various samples leaves no doubt that the fen silt and clay were deposited in a brackish area penetrated by high tides. Dr. Macfadyen thinks, from his examination of various samples of fen clay, that there seems to be indicated a transition from semi-marine silty clay to nearly freshwater siltless clay, immediately before the deposition of the overlying upper peat. A well-marked erosion surface is frequently found between the upper peat and overlying deposits; and the upper peat, though much destroyed through cultivation, was evidently continuous over the southern part of the fens. It is overlaid at its seaward margin by the thinned-out margin of the fen silts, which form a large area around the Wash and extend into the peat fens as roddons.

The wastage of peat has brought to light many old river-courses, some of them roddons, or the raised banks of laminated silt which meander through the peat fens. Subsequent work by members of the Fenland Research Committee has led to the suggestion that some roddons were levées, or naturally formed river-embankments raised above the general level of the countryside by flooding in the lower reaches of rivers. Much of the roddon-silt was formed in Romano-British times, and was deposited as it now lies, since Roman ware has been found in the lower part and there are traces of occupation-sites on the surface, in some places being superposed as the banks of the roddon were progressively raised.

In the fen silt bones of whale, seal, walrus and grampus have been found.

Fens silts and clays vary in consistency and different names have been given accordong to the predominant character, ' warp ' being used when sandy and ' buttery clay ' when smooth. *Scrobicularia* clay is so called because it contains an abundance of shells of that name. This clay indicates subsidence, since *Scrobicularia* flourishes only below mid-tide level; and samples from St. Germans, examined by Dr. Macfadyen, showed a richer content of foraminifera than any of the lower clays, and were thought to indicate appreciably more marine conditions.

Among the more recent deposits of the fenland is the Shell Marl, in beds varying in thickness from 1 to 5 ft., full of freshwater shells and the remains of ostracods and of the plant *Chara*. It was formed in the clear water of shallow meres, some of which persisted until recent historic time.

The following table shows the correlation of the Fenland deposits, the items being selected from the table prepared by Drs. H. Godwin and M. H. Clifford, 1940.

Chronology (approximate)	*Phases of Fen History*	*Archaeological Horizons*	*Major Features of the Period*	*Conditions of Sites* *Marginal*	*Middle*	*Seaward*
1,900 1,500	Drainage and Marshland Reclamation	Historic		Peat growth		Silt Local Peat
500 A.D. ....O... B.C.	Upper Silt and Meres	Romano-British	MARINE TRANSGRESSION	? Meres	Roddon Silts	Upper Silts
	Upper Peat	Iron Age Bronze Age Early Bronze Age	— Stagnation— Phase Brush wood on raised bogs Marginal Pine woods and tendency to form acidic (*Sphagnum*) peat [Wet phase]	Old Runs cut Pine and Yew in Fenwoods Some acidic peat	Roddon cut Fenwood ↑ Brush-wood ↑ Fen.	Channels Fen-wood Silt
? 1,500	Fen Clay		[Dry phase— Local woods] Shallow brackish lagoons EXTENSIVE BUT SHALLOW MARINE TRANSGRESSION	Fen woods	Fen clay	Silt
? 2,000 3,500 5,500 7,500	Lower Peat	Neolithic Mesolithic	Dry Fenwoods Peat formation becoming general in fens Peat forming only in river-channels, etc. Peat on Dogger Bank, etc.	Erosion channels cut Dry oak		Fenwoods

Interesting records of the variation in the thickness of peat have recently been made known by Major Gordon Fowler, who has discussed its wastage through drainage and cultivation. Measurements were taken from a post driven through 22 ft. of peat into the underlying Buttery Clay in Denton Fen, Huntingdonshire. In 1848 the top was at ground level, and thereafter the following wastages were recorded:

	Ft.	in.
1860	4	9
1870	7	8
1875	8	2
1892	10	2
1932	10	8

In 1932, the depth of peat was 11 ft. 4 in., but with good drainage and continuous cultivation the thickness would probably be not more than 6 ft. Over most of the area it is not much more than 3 ft., and the tendency is for wastage to continue under improved drainage and cultivation.

Beneath the surface of the peat in places are buried forests, of which five have been seen in the Isle of Ely. Among the trees of these forests are oak, fir, yew, willow and pines. Intermittent subsidence evidently gave rise to the succession of forests. In addition to the remains of plants and trees, the peat contains bones, insect-remains, chiefly the elytra of beetles, and Neolithic flint implements. All the bones are stained to a deep brown, and the fact that whole skeletons are sometimes found with the bones associated shows that there was little drifting: the animals just sank in the mire and died. Among the animals whose remains have been found in the peat are the extinct wild ox, the wolf, beaver, brown bear, otter, weasel, pelican and swan.

The Fenland deposits have been used for economic purposes. Peat has been dug extensively for fuel, the clays when mixed with sand are suitable for brick-making, and the Shell Marl has been used for manuring the land.

ALLUVIUM

Along the banks of most rivers are strips of alluvium of varying width. This is the latest material brought down by the streams and it forms areas of flat land so near the present level of the water that they are liable to be flooded in wet weather. The material is a silty deposit of sandy clay or peaty marl, in which there are occasional seams of gravel. In places it attains a thickness of 20 to 30 ft. Land- and freshwater-shells of recent species and bones of present-day animals are sometimes found in it. The depths of the Alluvium indicate that the land stood higher at one time.

Alluvial tracts form the chief meadow and grazing lands. From the evidence of humanly-fashioned implements found in and on alluvial deposits, they appear to date from Mesolithic times onwards.

BLOWN SAND; SHINGLE

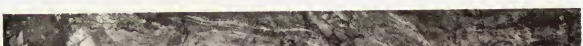
Accumulations of blown sand and shingle are important features in places along the coast, and are referred to in the chapter on Coastal Changes (p. 94).

A. THE ISLE OF ELY.

B. MORSTON SALT-MARSHES AND BLAKENEY ESKER.

(*For full explanation, see p. v.*)

A. CLIFF-SECTION AT BEESTON REGIS, NORFOLK.



B. 'CONTORTED DRIFT' IN CLIFF-SECTION AT BEESTON REGIS, NORFOLK.

(*For full explanation, see p. v.*)

VII. EARLY MAN

ONE OF THE most interesting features of the later geology of East Anglia is its connexion with the history of Early Man. Actual skeletal remains are rarities because the chances of their surviving destruction long enough to be incorporated in geological deposits were remote; but traces of Man's occupation were left behind in the forms of the tools that he used. These include hand-axes, flakes with trimmed edges used as scrapers for dressing skins, knife-blades, choppers for smashing bones, and gravers, all fashioned out of flint—the commonest and most characteristic rock-material of the area. Chiefly because of the abundance of flint and the suitability of conditions whereby worked flints were embedded, East Anglia has long been a most prolific hunting ground for the remains of Early Man's activities. It has proved, in fact, to be the meeting ground of geology and prehistoric archaeology.

The variety of workmanship displayed by the flint implements, and the manner of their occurrence, have provided a means of classification into successive 'cultures.' When implements occur plentifully at one place, and all bear evidence of a similar type of workmanship and have a general resemblance, the term 'industry' is applied to the group.

In East Anglia, as in certain other regions, these industries are found to follow one another in definite order. Thus they can be used, at any rate locally, as fossils determinative of the age of the deposits containing them; provided they are in a fresh condition, *i.e.* they bear no signs of having been derived from older deposits.

The term Stone Age has been used in a general way to indicate the time during which Early Man lived, and the four divisions recognized are the Eolithic (Greek, *eos*, dawn; *lithos*, stone), Palaeolithic (*palaios*, ancient), Mesolithic (*mesos*, middle) and Neolithic (*neos*, new).

Eoliths (Fig. 35B), regarded by some as the most primitive type of flint implements, were first recognized on the Chalk plateau of the North Downs of Kent.

Two chief divisions of the Palaeolithic age have been recognized, and the following sequence of cultures is established, the names being adopted from the places where they were first discovered.[1] Lower Palaeolithic; Pre-Chellian, Chellian (Abbevillian),[2] Acheulian, 'Mousterian' (including

[1]Chelles, on the Marne, above Paris.
St. Acheul, a suburb of Amiens.
Le Moustier, a rock-shelter in the Dordogne.
Clacton, Essex.
Le Vallois-Perret quarter, Paris.
La Madeleine, a rock-shelter in the Dordogne.
Aurignac, a cave in the Haute-Garonne.
Solutré, Saône-et-Loire.

[2]As many of the types of implements formerly included in the Chellian are now regarded as Acheulian, the term Abbevillian has been introduced to include only the earliest types.

Clactonian and Levalloisian),[1] Upper Palaeolithic: Aurignacian, Solutrian, Magdalenian.

The Mesolithic and Neolithic ages also comprise a number of cultures, but these will not be considered in detail since the implements are always found near the land surface, and few geological changes have taken place since Neolithic times.

In the Fenland, however, deposition has continued to a comparatively recent date, and some Mesolithic (Late Tardenoisian), Neolithic, and Early Bronze Age implements have been found in order of stratification at Peacock's Farm, Shippea Hill, near Ely.

In regard to the cultures mentioned above, it can be said that a gradual transition can be traced from the most primitive to the last of the Neolithic. Moreover it is now possible to correlate the sequence of cultures with successive geological deposits. Thus if the evidence for Red Crag implements be accepted it would appear that early Man inhabited the area before it was invaded by ice-sheets; it is certain, however, that he was a contemporary of the large mammals (elephants, hippopotamus, rhinoceros, bison, deer, etc.) that characterized the Pleistocene Period. At that time England was not separated from the Continent, what is now the North Sea being part of the valley of the old River Rhine.

As one would expect, Man's earliest efforts in making tools from flint did not result in the production of shapely implements. His first achievements were roughly-fashioned flakes and choppers, only distantly resembling what are easily recognized as genuine tools. It is not surprising then that controversy has long raged as to how far the flaking is natural or artificial, for Nature, as well as Man, can produce fracturing in flint. Man's handiwork, however, shows an orderly sequence in the blows on flint: the blows that produced natural flaking were fortuitous. Rarely has controversy, in stimulating investigation, been productive of more valuable results.

Eoliths have been found in the Stone Bed beneath the Red Crag in Suffolk; they are mostly abraded and therefore older than the Red Crag itself. Other eoliths, also abraded, have been found in the gravel underlying boulder clay at Ipswich.

Associated with eoliths in the Stone Bed of the Red Crag, are other types of flint implements slightly more advanced, to which the name pre-Chellian has been applied. These include flakes and choppers, and the beak-like forms which have been called rostro-carinates (Fig. 35A). As regards the last-named, one of the strongest arguments for their acceptance as humanly-fashioned implements is the repetition of this form which is observable in the flints of

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[1]In France, where the succession of cultures was established, the flake industry termed Mousterian, found in cave-deposits, was later than the Acheulian hand-axe industries; but investigations in Britain and elsewhere proved that the flake and hand-axe industries were contemporaneous. Thus one of the earliest flake-industries named after Clacton, in Essex (types until lately included in the general term Mousterian) appears to be synchronous with the Acheulian and possibly even with the Chellian; the later flake-industries known as the Levalloisian again covered in a broad sense by the term 'Mousterian', seem to have developed during Acheulian times and to have become the predominant industry of post-Acheulian, pre-Upper Palaeolithic times. Hand-axes were produced by trimming a nodule of flint and using the shaped core. Flake-implements were made from nodules so prepared that one blow would detach a flake suitable for use.

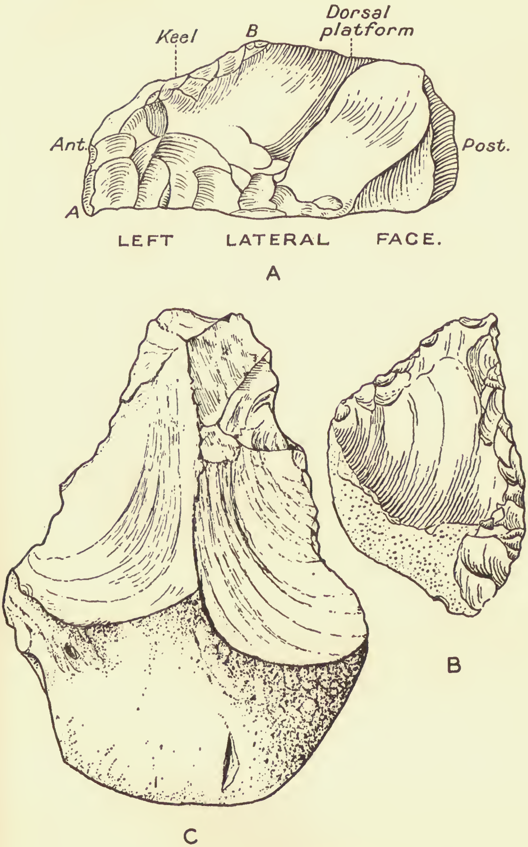

FIG. 35. *Flint Implements.*

A. Rostro-carinate flint. Left lateral face of Norwich Test Specimen. (After J. Reid Moir, *Phil. Trans. Roy. Soc.*, ser. B., vol. 209, p. 336, Fig. 4.) **B.** Eolith from Red Crag. (After M. C. Burkitt, ' The Old Stone Age ', 1933, p. 102, Fig. 2.) **C.** Hand-axe, Chellian type, Kempston, near Bedford. (Brit. Mus. (Nat. Hist.) Worthington Smith Coll., Regd. E.29.) A and B slightly reduced; C natural size.

the basement-beds of the Red Crag, the Norwich Crag, the Cromer Forest-bed, and of even later deposits. The rostro-carinate type of implement forms a connecting link between the eoliths and the Palaeolithic hand-axes. It should be noted, however, that eoliths and rostro-carinates are not accepted by all as of human workmanship. According to some investigators the oldest deposit in East Anglia yielding undoubted artefacts is the Cromer Forest-bed, in which hand-axes, choppers, scrapers, and points have been found. From the generally large size of these implements it is assumed that they were used by large-handed beings of considerable strength, and they have been recognized as early Chellian. It is probable that the Chellian culture continued into the first interglacial period, but few unrolled implements of the later stages of this industry have been found actually in place. One example (Fig. 35C) was obtained from river-gravel at Kempston, 2 miles south-west of Bedford. Another hand-axe definitely referable to the Chelles industry has been found in Cromer Till, but its provenance has been regarded by some geologists as doubtful. Rolled Chellian implements have been found in the Glacial Sands and Gravels, but rolled implements cannot be used for accurate dating of deposits; the criterion is that they must be fresh (*i.e.* unworn); then it may be assumed that the makers lived not far away.

The second period of glaciation intervened before the Acheulian industry was established in the area. Acheulian implements (Figs. 36A, B), the shape of which has been evolved by the gradual elimination of the keel, have been found in lake deposits and terrace gravels that were laid down by rivers during the second interglacial period. At three localities in Suffolk (Hoxne, Ipswich and High Lodge) implements have been found in beds of a definite order of succession. The position of the implement-bearing beds in the sequence and the nature of the associated deposits have provided useful data as to chronology and climatic conditions.

At Hoxne the succession, as interpreted by Reid Moir and C. Reid, begins with the Chalky-Jurassic Boulder Clay, which rests on glacial sand. A deep channel in this Boulder Clay was scoured out during the retreat of the ice, and through subsidence was turned into a shallow freshwater lake, on the floor of which 20 ft. of lacustrine deposits were accumulated. The lake became silted up, the climate was then temperate, vegetation flourished, and peat was formed. Meanwhile, the climate being more genial, Man and other animals were returning to the area. Further subsidence caused another 20 ft. of lacustrine beds to be deposited, and the climate became temporarily cold. Floods then laid down seams of gravel and brickearth which contain flint implements of an advanced Middle Acheulian industry, as well as bones of mammoth and reindeer. A layer of peat was then formed and 8 ft. of brickearth accumulated. The peat contains shells and plants indicating a temperate climate, and near the base of the brickearth is a ' floor ' or occupation-level with ' early Mousterian ' (Clactonian) implements with bones of horse, deer, beaver and elephant. The third glaciation cut short Man's occupation of the area, and a disturbed glacial deposit (Upper Chalky Drift) was laid down.

FIG. 36. *Flint Implements.*

A. Acheulian hand-axe. Whitlingham, Norwich. (After J. E. Sainty, *Proc. Prehistoric Soc. E. Anglia*, vol. v, pt. 2, 1926, Figs. 4a, 4b.) **B.** Late Acheulian hand-axe, Bramford Road, Ipswich. (After J. Reid Moir, *Proc. Prehist. Soc. E. Anglia*, vol. vi, pt. 3, 1930, p. 190, Fig. 8.) Both one-half natural size.

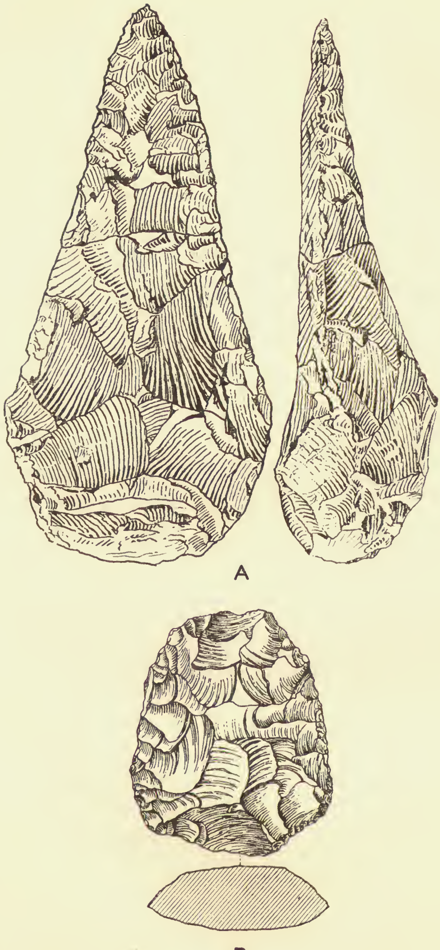

FIG. 36. *Flint Implements.*

The Clactonian industry, like the Levalloisian (Fig. 37 C), marked an active development of the technique of fashioning flakes into implements. It appears to have been contemporaneous with the Acheulian culture, in which the dominant forms were hand-axes fashioned chiefly from the ' cores ' reduced from dressing the flints.

The section at Ipswich (Foxhall Road) tells a similar story of a silted-up lake, the deposits here, as at Hoxne, resting on the boulder clay of the second glaciation. The flint implements provide evidence of an encampment of Acheulian Man, because hammer-stones and numerous flakes were found in an unworn condition.

At High Lodge, 2½ miles north-east of Mildenhall, unworn ' Mousterian ' implements have been found in brickearth on the side of a hill overlooking the Fens, at a height of 100 ft. above sea-level. Here again brickearth was deposited in a hollow in the Chalky Boulder Clay and the flint implements show that ' Mousterian ' Man lived in the area between the second and third glaciations, because the brickearth containing them is covered by Upper Chalky Drift. Only one half of the brickearth-filled hollow is preserved, however, the other part having been eroded.

In addition to the implements associated with the glacial sequence, examples of Acheulian and later industries have been found in valley deposits. Certain of the older rivers of East Anglia were evidently fed by retreating glaciers and the glacial materials were re-sorted, and spread along the valley-slopes. The order of events is not always clear, but as regards the main valley-systems of Norfolk and Suffolk it is obvious that they were initiated after the deposition of the Norwich Brickearth but before the Chalky Jurassic Boulder Clay was laid down.

Early Man probably lived at no great distance from the ice-front and floods from ice-melting would wash his implements into the gravels. During more temperate phases Man dwelt close to the river-banks, and so his discarded tools got washed into the river-bed. In the valley of the Yare, at Whitlingham, near Norwich, Acheulian implements have been found in river-gravels at 40 to 45 ft. above the present stream. The more primitive forms are worn, but the evolved Middle Acheulian examples are unabraded. Evidently this spread is later in age than the Chalky Boulder Clay that occupies the valley-slopes at a higher level.

The Gipping Valley in Suffolk, excavated in a plateau spread with glacial sands and gravels of the first glaciation, also provides evidence of occupation by Acheulian and ' Mousterian ' Man, both on the valley-slopes and on the alluvial flats (which are now below the level of the present river). Higher up the valley-system in terrace deposits, are ' floors ' (or occupation-levels) of ' Mousterian ' and Aurignacian industries.

Fig. 37. *Flint Implements.*

A. Clactonian side-scraper, High Lodge, Mildenhall, Suffolk. Length 3.1 ins. (After R. A. Smith, ' The Sturge Collection ' (Britain) *British Museum Catalogue*, 1931, p. 27, Fig. 4.) **B.** Clactonian side-scraper, High Lodge. Length 6 in. (After R. A. Smith, *op.cit.*, p. 27, Fig. 2.) **C.** Levalloisian flake-implement, Ipswich. Natural size. (After J. Reid Moir, *Journ. Roy. Anthrop. Inst.*, vol. xlvii, 1917, p. 396, Fig. 10.) **D.** Aurignacian scraper, Ipswich. Natural size. (After J. Reid Moir, *loc. cit.*, p. 404, Fig. 35.)

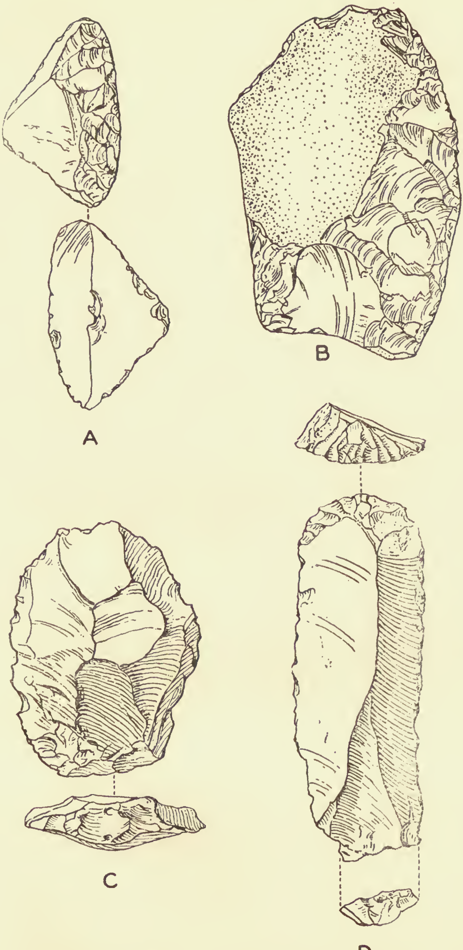

FIG. 37. *Flint Implements.*

In the Cam valley, worn Chellian and Acheulian implements have been found in the valley gravels, Lower Barnwell Village Beds, and the lower evenly-bedded gravels of the Traveller's Rest Pit. Late Acheulian and early Mousterian (Levalloisian) implements occur in the succeeding unevenly-bedded gravels of the Traveller's Rest Pit. Similar sequences are observable in the gravels of the Ouse.

A change in the form of flint implements is noticeable after the last of the ' Mousterian ' series of industries, for Early Man then began to try his art in carving and graving bone, in fishing, and (in other countries) in painting on the walls of caverns. The large and shapely hand-axe gave place first to smaller graceful forms, and then to thick and squat implements (early Aurignacian); afterwards came the long and narrow forms that characterized late Aurignacian times. Other implements (scrapers, planes, and points for engraving) show a reduction in size but an elaboration in workmanship.

The new art marked the commencement of late Palaeolithic times, which include Aurignacian, Solutrian, and Magdalenian cultures (Figs. 37 D, 38 A & B).

A section which illustrates the deposits of this age was exposed in Messrs. Bolton and Co.'s brickpit, on the north-west of Ipswich, and was described by J. Reid Moir. The site is in a streamless tributary valley of the Gipping, the valley having been excavated by the water set free during the melting of the glacier that formed the Upper Boulder Clay. The valley cuts through the Upper Boulder Clay, the Glacial Gravel, and the Red Crag sands, the bottom lying on the London Clay. In the depression thus produced is a series of beds containing implements of successive industries. The following sequence was determined by Reid Moir, the beds being arranged in descending order:

13. Surface soil, with Neolithic implements, to 1 ft.
12. Stony hill-wash, with early Solutrian blades, to 8 ft.
11. *Floor D*, of late Aurignacian age.
10. Stoneless loamy sand, to 3 ft.
9. Peat to 9 in.
8. *Floor C*, of late Mousterian or early Aurignacian age: many flint implements, extensive hearths, burnt flints, bones (many cut, scraped, or gnawed) of man, elephant, deer, horse, pig and goat, and rough pottery.
7. Clay with many flints (Upper Chalky Drift), to 1 ft.
6. Traces of occupation-level in upper part of (5); with quartzite scraper.
5. Clay; like London Clay but much more recent, to 6 ft.
4. Bluish sandy loam, roughly stratified to 2½ ft.
3. An ancient occupation-level (*Floor B*), with typical Mousterian implements and some quartzite hammer-stones.
2. Chalky Boulder Clay (the equivalent to that underlying the Palaeolithic deposits at Foxhall Road, Ipswich, Hoxne, and High Lodge), to 8 ft.
1. An ancient occupation-level (*Floor A*); with indeterminate flakes and burnt flints.

The occupation-levels in this valley are thus intermediate in age between the formation of the boulder clay of the third glaciation and the spreading of the hill-wash. From the fact that the hill-wash is present as terraces on either side of the valley and is not spread over the floor, it is assumed that this deposit must have been washed out of the lower levels and that this was effected through glacial agency. Reid Moir pointed out that this must have taken place during the final stages of the fourth glaciation of East Anglia. Similar terraces have been observed in numerous tributary valleys in Suffolk.

A few beautifully-fashioned blades resembling those of the Solutrian industry (Fig. 38 A) have been found in the Fen district and Suffolk, either in superficial deposits or on the surface.

FIG. 38. *Flint Implements.*

A. Solutrian blade, Ipswich. (After J. Reid Moir, 'The Antiquity of Man in East Anglia', 1927, p. 113.) **B.** Magdalenian blade, Ipswich. (After J. Reid Moir, *Proc. Prehist. Soc. E. Anglia*, vol. vi, pt. 3, 1930, p. 202, Fig. 26.) Both two-thirds natural size.

A decline in the standard of workmanship in flint implements is noticeable in those made by Magdalenian man, but his skill was doubtless transferred to other directions. Certain finds in superficial deposits in East Anglia have been attributed to this phase. Magdalenian implements have also been found near the surface in the Gipping valley and in alluvial mud in the submerged forest about 30 ft. below O.D. at the mouth of the Orwell. The boulder clay of the fourth glaciation (which did not extend much further inland than the north-west corner of Norfolk and was possibly of Magdalenian age) was deposited near Hunstanton; the great glaciations ended, and with them the Palaeolithic cultures. Implements of later industries are found near the surface of the ground, but as has been noted, few geological changes other than an important uplift in Mesolithic times, followed by submergence to 50 ft. have taken place since Palaeolithic times. The uplift referred to converted the southern part of the North Sea into land, and the Maglemose people migrated from Denmark into eastern England. A good example of a Maglemosian settlement, represented by ' floors ' of implements, was found at Kelling Heath, in Norfolk.

[While this edition was in the press a preliminary account of the results of investigation of the pollen-content of the Interglacial beds at Hoxne was published by Mr. R. G. West (*Nature*, vol. 173, p. 187, January 30, 1954). The results, which were confirmed by a number of borings, show that Reid's Lacustrine Bed and his Palaeolithic Loam (or so-called ' upper temperate brickearth ') are of the same age, although assigned to different positions in the composite sequence. A full account of the stratigraphy, palaeobotany and archaeological stratification, which is in preparation at the Subdepartment of Quaternary Research in the Botany School at Cambridge, is expected to be published in due course, together with some of the consequences for the revaluation of the East Anglian glacial sequence as a whole.

The deposits at Hoxne and other localities in East Anglia, as also the glacial Drifts in general, have been discussed, from a different angle, by Mr. R. G. Carruthers in his *Glacial Drifts and the Undermelt Theory*, Newcastle-upon-Tyne, 1953).]

VIII. STRUCTURE

THE GEOLOGICAL STRUCTURE of this part of England is simple. As has been noted, the oldest of the Solid strata (the Jurassic) crop out in the west and are inclined at a low angle towards the south-east, so that they pass under newer strata in that direction. The Lower Greensand rests for the most part unconformably on the Jurassic strata because of local uplift that occurred before it was laid down; consequently it rests on different members of the Upper Jurassic series.

In the south-western part of our area the Cretaceous formations (Lower Greensand, Gault, and Chalk) follow the same general arrangement as the Jurassic strata, but in Suffolk the strike of the Chalk swings round to the north and the direction of dip changes accordingly. In southern Suffolk the strike of the Chalk is from west-south-west to east-north-east; in Mid-Suffolk it runs due north; while in northern Norfolk it changes to north-north-west. The dip of the Chalk, like that of the earlier formations, is low; but becomes more pronounced towards the east.

The small area of Eocene beds in the south-eastern part of the area, between the Orwell and the Stour, forms the northern fringe of these beds in the London basin. Eocene beds rest on a bevelled surface of the Chalk and strike obliquely across several of the higher zones; they dip gently to the south-east with an inclination of about 20 ft. to the mile. Underground the Eocene beds extend to Eastern Norfolk, where again they rest on a bevelled surface of the Chalk.

The presence of an underground land-mass of ancient (Palaeozoic) rocks has been proved by the evidence of deep borings. Palaeozoic rocks were encountered in the borings at Stutton (near the margin of the area south of Ipswich), Lowestoft, Culford, near Bury St. Edmunds, and Harwich, just outside the area. At Stutton the Palaeozoic floor was struck at a depth of 974 ft. below O.D., where the Gault rests directly on rocks which are probably Upper Silurian (Ludlow) or Downtonian. At Lowestoft the Lower Greensand was found to rest on Palaeozoic rocks (possibly Silurian) at a depth of 1,615 ft. below O.D. The Palaeozoic floor at Culford was struck at 527 ft. where it was overlain by Lower Greensand, but there was no definite evidence of the age of the older rocks. Palaeozoic rocks, again of indeterminate age, although formerly thought to be Carboniferous, were found at 1,013 ft. below O.D. at Harwich, where they were overlain directly by Gault.

A deep boring at Norwich passed through 12 ft. of Superficial Deposits, 1,152 ft. of Chalk, 6 ft. of Upper Greensand and 36 ft. of Gault, but did not reach the Palaeozoic floor. Another one at Coombs, near Stowmarket, also stopped short of the floor, after passing through 57 ft. of Superficial Deposits, 817 ft. of Chalk, and 21 ft. of Upper Greensand and Gault.

The small number of deep borings in our area thus provide only limited data concerning the Palaeozoic floor under East Anglia, but our knowledge of the underground geology has been considerably extended by the seismic investigations undertaken by the Department of Geodesy and Geophysics at Cambridge. The area covered by these investigations included part of East Anglia west and south of Bridgham (6 miles N.E. of Thetford) and extended westwards to Calvert (Bucks.) and southward to the London area. In connexion with this work the core-samples from the earlier borings were re-examined.

Records of elastic waves from explosions were taken at selected stations and were interpreted in relation to the contours of Jurassic and Cretaceous strata plotted from data obtained from boreholes and outcrops. In our area the contours of the Palaeozoic floor were plotted from records taken at seismic stations at the following places; the calculated depth of the floor in feet below O.D. is given in each case. Feltwell (–830), Leighton (–920), Madingley (–740), Houghton Conquest (–400), Fenstanton (–500), Bourn (–560), Bassingbourn (–590), Pertenhall (–670), Cambridge (–360), Great Staughton (–670), Tempsford (–800), Arlesey (–560). All these stations, with the exception of Feltwell, gave a refracted wave from the Great Oolite as well as from the Palaeozoic floor.

Seismic records at the following stations indicate that the Chalk is underlain by Gault and Greensand, which rest directly on the Palaeozoic : Bridgham (–690), Kentford (–690), Lakenheath (–810), Swaffham Prior (–500), Culford (–527) and Fulbourn (–480). The seismic calculation for Cambridge was confirmed in 1953 by a borehole which proved Carboniferous Limestone under Lower Lias at –355 ft.

Although the Palaeozoic floor as a whole appears to be of gentle relief, the contours plotted from these figures show an oval rise (–360 O.D.) under Cambridge, extending and falling eastwards, its lower slopes forming a narrow ridge in a north-easterly direction past Culford and Bridgham. The north-west flank of this rise slopes sharply towards Madingley, north of which the floor opens out gently to the –800-ft. line and falls gradually northwards. To the south of Cambridge the lower slopes of the ridge spread out south-westwards on the west of Saffron Walden. West of Cambridge there is a depression reaching a depth of 800 ft. in a restricted area around Tempsford. North and south of the Tempsford depression the floor slopes downwards gradually. To the west-south-west of the depression the floor rises gradually over a broad projecting prominence, with its axis running in that direction, until it reaches –153 ft. O.D. at Calvert (Bucks.), 37 miles distant. East and south-east of the Cambridge-Fulbourn-Calvert rise the floor slopes gently towards the coast, the slope being more gentle towards Harwich (–1,013 ft. O.D.) than it is towards Lowestoft (–1,615 ft. O.D.). Resting on the Palaeozoic floor are Jurassic and Cretaceous strata with an easterly or south-easterly dip of less than one degree. The evidence of boreholes shows that the Jurassic strata thin eastwards and disappear, leaving Cretaceous strata resting directly on the Palaeozoic, and data concerning the depths and thicknesses of these strata were used in conjunction with seismic records to plot the underground distribution of the various formations.. Below Cambridge the total thickness of Jurassic strata (from Ampthill Clay to Lower Lias) was 264 ft.

One conclusion drawn from these seismic investigations is that the irregularities in the floor are not reflected in the structure of the Mesozoic cover. This conclusion is interesting, since it shows that there is little evidence of Charnian (N.W.-S.E.) folding, which was thought to produce a thinning of the Lower Greensand near Sandy. The results of plotting contours show that formation to be thicker near Sandy than it is a few miles to the north and south.

Recently, in the course of a systematic study of the possibilities of oil-fields in England, by the geological staff of the Anglo-Iranian Oil Company, an exploratory boring was put down at North Creake, 11 miles east-south-east of Hunstanton. Theoretically it was possible that the zone of oil-bearing conditions which the geologists had proved in Nottinghamshire, might extend into northern Norfolk. The results of the boring, however, showed Pre-Cambrian rocks at a depth of 2,435 ft., directly overlain by Bunter Sandstone. The strata passed through in the boring were: Chalk 471 ft., Upper Greensand 10 ft., Red Chalk 6 ft., Lower Greensand 216 ft., Kimmeridge Clay 160 ft., Ampthill Clay 85 ft., Oxford Clay and Kellaways Beds 184 ft., Cornbrash 6 ft., Great Oolite Series 97 ft., Lias and Rhaetic 555 ft., Keuper 513 ft., Bunter 132 ft., Pre-Cambrian penetrated to 197 ft.

From the data provided by this boring Dr. P. E. Kent in 1947 could indicate the probable limits of the Mesozoic formations on the northern part of the Palaeozoic floor. Thus the Trias may be supposed to trend approximately east-north-east from southern Northamptonshire to the Norfolk coast, and its thickness is such that North Creake is evidently well to the north of the feather-edge of the formation; and accordingly its south-eastern limit has been drawn about 15 miles to the north of Culford and of Lowestoft. The lower part (the Bunter) is probably overlapped a few miles south of North Creake, the Keuper overlapping it and transgressing beyond it across the Palaeozoic floor. The Rhaetic is so imperfectly represented at North Creake that it is most likely overlapped by the Lias, over the area to the east and south. The earlier Jurassic beds were, in the main, deposited in conformable sequence; they thin southwards and, through upwarping of the Palaeozoic floor were truncated in that direction by the transgression of the Great Oolite Series. At North Creake there is no representation of either the Inferior Oolite or the Northampton Sands; most of the Upper Lias has been eroded and only the Middle and Lower Lias remain, but the 1953 boring record at Cambridge shows that the Lower Lias is still represented there and that the Great Oolite itself is present although the lowest members of the Series were already attenuated at Southery. Subsequently there was widespread upward movement, as indicated by the sandy facies of the Kellaway Beds, the south-eastern limit of these beds running with gentle curvature from south of Bedford to the north-east coast of Norfolk. After the formation of the Kellaways Beds gradual sinking was accompanied by the deposition of the Oxford Clay, the shore-line extending again to the south-east, reaching to about 15 miles south-east of Bedford and running north-eastwards to the coast north of Lowestoft. Although the zones at the bottom and the top are poorly developed this formation evidently extended nearly so far south as Culford. The clay facies continued while the Ampthill and Kimmeridge Clays were laid down, and the further extension of these formations was evidently controlled by uplift and erosion, so their south-eastern limits are plotted successively further to the north.

So far as can be seen, the earliest Cretaceous beds in the area (the Neocomian), which also overlap on the Palaeozoic floor, rest almost parallel on the Kimmeridge Clay, thus indicating an absence of such tilting as occurred before earlier transgressions of the sea. The Neocomian beds, however, appear to be truncated obliquely and the Sandringham Sands seem to be progressively overstepped south of King's Lynn, the transgressive beds involving the upper part of the Lower Greensand, the Gault and the Chalk.

In general, the Mesozoic formations on the north side of the Palaeozoic floor show similarity to those on the south side, under the Weald, with the same transgression of the Lias beyond the Trias, and of the Great Oolite beyond the Lias.

The effects of movement of an underground axis in Suffolk during Tertiary times have been studied by Prof. Boswell and are illustrated by the accompanying figure (Fig. 39).

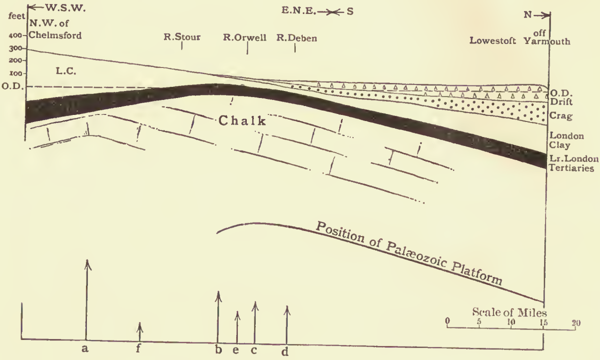

FIG. 39. *Section across the north-west and south-east axis of instability in East Anglia.*

Vertical scale: 1 inch = 1,000 ft. (After P. G. H. Boswell, *Quart. Journ. Geol. Soc.*, vol. lxxi, 1915, p. 550, Fig. 4.)

Position of axis of instability in Tertiary times.

a = Change of strike of Chalk zones (pre-Eocene folding).
b = Change of strike of Chalk surface-contours (pre-Eocene and Eocene denudation).
c = Anticlinal axis shown by the lines of equal thickness of the Lower Tertiary beds.
d = Anticlinal axis shown by the lines of equal thickness of the London Clay.
e = Anticlinal axis of the Crag deposits.
f = Position of maximum post-Glacial rejuvenation of the river-systems, due to uplift.

The movements that were in progress in Post-Pliocene times, and are connected with the increasingly boreal character of the Crag deposits as they are traced northwards have been referred to on p. 44.

Local uplift still continued in post-Glacial times, however, for the gradient-curves of the rivers of Suffolk and northern Essex show different evidence of rejuvenation. The Norfolk rivers—the Bure, the Wensum, and the Yare—show no evidence of rejuvenation, neither does the Waveney. Indications of rejuvenation in the Alde are slight, but the Deben, the Gipping and the Stour show marked rejuvenation, the Deben to about the 25-ft. contour and the other two to about the 50-ft. contour.

IX. PHYSICAL FEATURES

ALTHOUGH NOT AN area of strong relief, a wide range of physical features is represented in the part of the country under description, and it will be seen that these are intimately connected with the geological structure. Only in the Chalk hills of south Bedfordshire do the contours exceed 500 ft. O.D., and 800 ft. is reached only in a few detached areas; the greater part of the country is below the 300-ft. contour. Most of the low-lying ground in the western part lies within the basin of the Great Ouse, a small part on the north-west being drained by the Welland and the Nene. The rivers of the East Anglian Plain (occupying the eastern part of the area) flow out on the east coast.

Several well-known geographical units and a variety of scenic types are included in the area under description. Among them are the Fens, the Broads, the Brecks, the Cromer Ridge and an area of downland. Of the chief geological regions it includes a part of the great Jurassic belt that runs in a north-easterly direction across England, a part of the Chalk belt, and the home of the Crag deposits (Pl. I).

Nearly all the area in the Jurassic belt belongs to the great clay vale of Central England and is terminated by the Fens. This belt forms a plain relieved here and there by gentle elevations caused by patches of Drift. Bordering the clay vale, in the south-west of our area, and extending from Leighton Buzzard, north-eastwards through Woburn, Ampthill, Shefford, Sandy and Potton, is a hilly ridge determined by the presence of the Lower Greensand. Over most of its area it forms a range of undulating hills producing agreeable woodland scenery. Here and there its barren sandy surface bears characteristic fir plantations. On the right bank of the Ivel near Sandy this formation gives rise to a picturesque escarpment. Where it comes to the surface in western Norfolk, from Castle Rising, past Sandringham, to Heacham, the Lower Greensand is again associated with similar type country—sandy, heather-clad uplands with patches of fir and open commons with poor soil (Pl. II A). On the eastern border of the ridge that commences near Leighton Buzzard, and extending north-eastwards to Soham, is another clay vale formed by the Gault but interrupted near Cambridge by outlying areas of Chalk which give rise to slightly higher ground.

As in other parts of the country the clay vale of the Gault is bounded by the rising ground of the Chalk. The typical scenery of the Chalk is high ground sculptured here and there by coombes and dry valleys, and with steep slopes and softly-rounded outlines, the result of gradual and long-continued subaerial denudation. Such features are to be seen only in the south-western part of our area, the country around Dunstable and Luton, extending past Royston. The Barton Hills and the Gog Magog Hills are also on the Chalk, while near Newmarket the country is typical downland, bare of trees and clad with short turf. In the area south-west of Newmarket definite surface ' features ' due to the superior hardness of the Totternhoe Stone, the Melbourn Rock, and the Chalk Rock are observable. The outlines of the Chalk in Norfolk and bordering the Fens are much less pronounced than in other parts of the country on account of considerable wearing-down during the Ice Age.

In Bedfordshire most of the Chalk is free of Drift but patches of Clay-with-flints occur here and there on the higher ground. Uncovered Chalk also occurs as a narrow border, a few miles in width, along its western margin i Cambridgeshire and Norfolk. Over the rest of the area the Chalk is covere by a mantle of Drift deposits (Boulder Clay, Sands and Gravels, etc.) whic have prevented the development of the usual features of Chalk country an imparted their own characters to the scenery. Most of Norfolk, Suffolk an Cambridgeshire is plastered over with Boulder Clay. This deposit also cove most of Huntingdonshire and Bedfordshire, but here it rests on an almost fl expanse of clay. Over the greater part of Norfolk and Suffolk it forms featureless plateau dissected by gently-sloping valleys, where the streams ha cut through the widespread covering of glacial deposits and exposed the unde lying substrata. Towards the east this plateau country is relieved here an there by low hills and gently undulating mounds of glacial debris. Glaci deposits, either Boulder Clay or Glacial Sands and Gravel, cover nearly th whole area of the Crag, which overlies the Chalk and Eocene beds in the easter parts of Norfolk and Suffolk.

One notable feature near the north Norfolk coast is the Cromer Ridg (Pl. V A), which extends from Holt to the coast at Mundesley, with an averag width of five miles. Messrs. Baden-Powell and Reid Moir described its prese outward form as due to a veneer of Blakeney gravel banked against the erode side of the ridge, its uneven bedding following the slope of the hill. There a substantial thickness of an earlier, horizontally well-bedded gravel (Briton Lane gravel) in the interior of the ridge, and a chalky boulder clay also take part in the structure. The ridge was at one time thought to be a moraine, bu it is evidently of compound origin. Its great height (more than 300 ft.) is partl due to contortion. Over most of its area the slopes are smooth and even, bu the ridge is trenched by deep valleys on its northern slope.

Where the Glacial Sands and Gravel form the surface, as over large tract between Norwich and the northern coast of Norfolk, wide and comparativel flat areas of heathland are formed. The sands and gravels are also spread i narrow and discontinuous tracts near and along the east coast from Yarmout to Aldeburgh. Near the latter place it spreads over a wider inland and extend over the low plateau past Woodbridge to Ipswich.

Some parts of East Anglia show surface features that are to be seen nowher else in England. Among these may be noted the Brecklands and the Broad The Brecklands are wild open heaths (rising in places to 350 ft. O.D.) forme where only a thin capping of sand and gravel covers the Chalk and gives ris to barren sandy soil with but little surface water. This type of country (wher sandstorms are liable to occur) is seen around Thetford, and stretches north eastwards to Watton and East Harling.

Among the heaths in two shallow valleys north of Thetford are sever small open meres, which are dry at times. These meres, with certain associate ponds, probably originated through the partial blocking of the floors o swallow holes by clay transported from glacial beds through erosion.

An appreciable part of the area under review is occupied by Fen deposit which form a large tract of flat low-lying country (Pl. VIII B), almost dead level towards the north but slightly relieved in the south by low ' islands ' (El March, etc.). As is well known, this famous area was formerly covered by th sea. A glance at the geological map of England makes it obvious that th Chalk of Norfolk was once continuous with that of Lincolnshire. This ridge o

A. ORMESBY BROAD, NORFOLK.

B. FENLAND. GUYHIRN, CAMBRIDGESHIRE.

(*For full explanation, see p. v.*)

Chalk was worn away by the action of rivers, the sea, and by ice. Most of the Fenland, however, was carved out of an area of soft Jurassic clays—the Oxford, Ampthill, and Kimmeridge Clays. The whole area has been occupied more than once by the invading sea and has become gradually silted up. It is still protected from the sea by artificial banking. A large part of it is reclaimed land, drained by ditches or ' lodes ' which conduct water to pumping stations; here it is forced into channels and thence carried to sea. Three types of land are to be recognized in the Fens, gravel-land, peat-land and reclaimed silt-land. About half the area is occupied by silt-land, which stretches with uneven surface from the centre to the north. Peat-land is marked by a perfectly even surface. The higher land is formed by accumulations of gravel, and usually marks the sites of villages.

The Broads (Pl. VIII A) are stretches of open water situated in definite relationships to the channels of the three chief rivers of East Norfolk, the Bure, the Yare, and their tributaries, the broads of the Waveney lying just over the Suffolk border. Until recently they were generally regarded as natural features, due partly to subsidence of the area in Neolithic times and partly to the silting that followed the barring of the mouths of the rivers by sediment piled up by the south-flowing tides. A new outlook has been introduced largely through the work of Dr. Godwin on the southern Fenland, and investigations carried out in the Broads by Mr. J. N. Jennings and Dr. J. M. Lambert, and the view now taken is that most of them had an artificial origin. This conclusion has been reached through a study of the alluvium laid down during the formation of the valleys in Post-glacial times. The necessary data were obtained by means of borings put down at frequent intervals, and the results indicate a marine invasion of the valleys, probably during early Iron Age or Roman times. This marine episode produced a deposit of clay, which covered existing peat on the floors of the valleys, occupying the whole width downstream and petering out upstream. A margin of peat was left in parts beyond the edge of the clay. After the retreat of the sea the continued accumulation of peat covered the clay and added to the previous peat between the clay-margin and the upland valley margin. It is thought that excavation of peat, generally to a depth of 10 to 12 ft., over the area where it was most profitable, that is, where no clay intervened, left basins which were subsequently flooded after the abandonment of the workings. At first the broads must have been deep and their margins sharp (boring records showing the presence of steep-sided peninsulas, islands and ridges of peat) but accumulation of mud has caused shallowing, and encroachment of vegetation has produced their present appearance. Large areas of fenland between the broads have been dug superficially from time to time, in many cases directly from the areas of deeper basins, thus extending their water surface. The peat industry was of considerable importance up to the end of the 19th century.

X. COASTAL CHANGES

THE LAST EVENT of geological importance in our area was a submergence of the land in Neolithic times. Evidences of this are furnished by submerged forests on the coast, as for example at Brancaster, and by drowned river valleys. Subsequent changes were due to a large extent to the nature of the strata that form the cliffs; and as these are nearly all of soft or loosely-aggregated material, erosion has been extensive over a large part of the coast. The materials thus worn away have been moved by long-shore currents and waves and deposited across estuaries, with the result that rivers have been deflected by shingle spits. In some places the shifting of sand banks has allowed the waves to attack the land; while in others the accumulation of blown sand forms protective dunes.

The prominent north-west corner of Norfolk, near Hunstanton, stands out because the cliffs are formed of resistant Chalk, with underlying Red Chalk and Carstone. The Chalk, dipping very gently eastwards, extends as a ridge along the northern coast of Norfolk from Hunstanton to Weybourne. During Neolithic times it was probably a cliff; since then an enormous amount of sand has been brought down the east coast, and is now underneath the marshes and extends a long distance out to sea. Between Old Hunstanton and Weybourne is a stretch of marshland coast that forms a definite unit and illustrates admirably the processes of sedimentation as influenced by the development of vegetation on tidal lands. This area has been studied intensively by Prof. J. A. Steers, whose publications have added much to our knowledge. Blakeney Point and Scolt Head Island are the two principal headlands of shingle and dunes on this part of the coast and both originated through beach-drifting, the pebbles being shifted gradually westwards by the dominant waves, which approach obliquely.

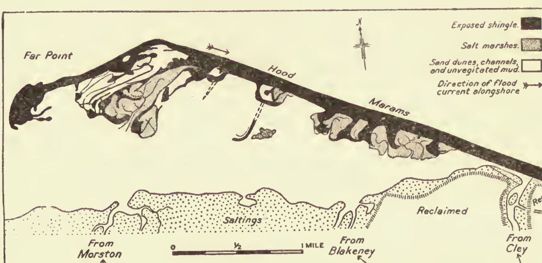

FIG. 40. *Development of Blakeney Point.*
(After F. W. Oliver, *Trans. Norfolk & Norwich Naturalists' Soc.*, vol. xi, pt. 5, 1924.)

The shingle-bar of Blakeney (Fig. 40) begins at Weybourne and extends westward for nearly 9 miles. Its constituent pebbles are nearly all of flint with about one per cent of Scottish and Scandinavian erratics, and it is largely covered with sand dunes. As the main bar grew it developed lateral bars on its inner edge, these bars being directed landwards, and arranged in groups (*e.g.* the Marams or Marrams).

Scolt Head Island (Fig. 41) is separated from the mainland by a channel—Norton Creek. It consists of a main shingle-beach, with dunes, trending parallel with the sea, and a series of lateral ridges (partially dune-covered) running landwards from the main ridge. These lateral ridges, as on Blakeney Point, represent former terminations. Often there is no true island at low tides.

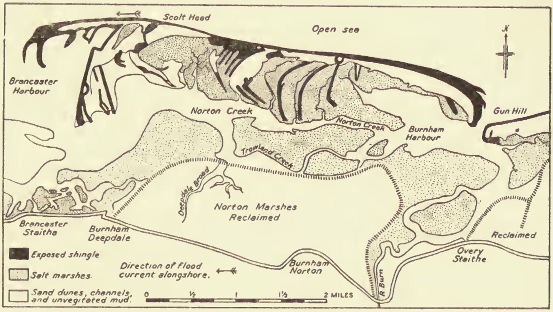

FIG. 41. *Structure of Scolt Head Island.*
(Adapted from F. W. Oliver, *loc. cit.*)

Within the shingle-bars on both Blakeney Point and Scolt Head Island are tracts of salt-marsh, usually on a foundation of sand. Part of this marshland is low marsh with bare mud-flats, and part is high marsh with occasional salt-pans, or pools of saline water, the unevaporated residue of water trapped at high tides (Pl. VI B.)

Recent studies on the formation of this marshland have proved very instructive. Under the protective shelter of the shingle-bars and dunes, tracts of sand have formed a suitable surface on which silt, brought in by high tides, has been deposited as a muddy film. Colonization of the sand and mud by plants germinated from seeds distributed by various agencies was the next stage, and with the growth of plants the speed of sedimentation increased because the plants check the flow of the water. As the plants spread the marsh grows higher, its accretion being assisted from time to time by blown sand. Meanwhile, a system of channels is developed with the growth of the marsh. The vegetation having spread from centres has encroached on uncovered spaces and has left here and there well-defined pools, the salt-pans.

The plants that occupy these changing areas form definite assemblages dependent on the nature of the material in which they are rooted and on the height of the marsh. In addition to the changes going on within the marshland, there is, on both Blakeney Point and Scolt Head Island, a gradual rolling movement landwards of the main shingle-bars, which thus slowly encroach on the marshland within.

Before the war the westward growth in both places was rapid. Measurements taken at Scolt Head Island show an average growth of 283 ft. between

1886 and 1904, and 150 ft. between 1904 and 1925. Since about 1938 Scolt dunes have retreated, not advanced, although there still remains a patch of dune at Far Point.

Similar coastal features (the development of shingle-bars, dunes, and salt-marshes) are to be seen along the shore between Old Hunstanton and Brancaster, but human activity, such as the building of sea-walls, has modified the effects of natural factors. New and ephemeral features observed along this shore have, however, thrown much light on the early growth of Scolt Head Island and Blakeney Point. The recent changes are generally similar to those that produced Scolt Head Island, but on the west of Scolt Head Island there is neither the quantity of shingle nor the conditions suitable for the development of such an extensive structure.

Observations on the rate of sedimentation during the period from 1935-1947, in the salt-marshes of Scolt Head Island, have been made by Prof. Steers. These marshes are formed between the lateral shingle ridges of the main island and run down to Norton Creek, the channel with numerous creeks running into it, through which the tidal silt is carried to the marshes. Prof. Steers finds that the rate of accretion is usually highest on the lowest marshes, and that the greatest amount of accretion is usually near the creeks. Sedimentation is slow until a marsh has developed a fairly thick cover of vegetation and has already gathered a spread of mud on it; and after a marsh attains a certain height the amount of tidal flooding falls off and continues so to do as the marsh rises higher. Thus there is a period of some length during which the most rapid growth occurs. The highest measurements, taken at Missel Marsh, where accretion is evidently near its maximum rate, shows sedimentation at the average rate of more than ·8 cm. per annum for the last 12 years.

At Weybourne the marshland comes to an end, and thence eastwards and southwards the coast is bordered by cliffs of varying height and has been subject to considerable erosion. At Happisburgh the Broadland commences, and between there and Caister are low-lying areas, protected from the sea by shingle bars, alternating with short stretches of cliff.

FIG. 42. *Diagram to illustrate the evolution of Scolt Head Island.*

The heavy line represents the present outline. The more important laterals are shown, but dunes are not indicated. Dotted lines are hypothetical and the letters a, b, c, d, and e, indicate the probable order of formation of the ridges. The ridge 1 - - - - -1? was the first-formed lateral. (After J. A. Steers, 'A Note on the Name "Scolt" and Physiography and Evolution of Scolt Head Island', Norwich, 1934, p. 46, Fig. 5.)

South of Caister the southward drift of beach-material becomes an important factor in coastal development, for between this point and the south-eastern extremity of our area it gives rise to extensive shingle and sand-pits. One such accumulation (which was largely responsible for the silting up of the Broads) was formed across the Yare-Waveney estuary, and about the year 1,000 A.D. a fishing settlement was formed, which in time grew into the town of Yarmouth. Continued drifting of the spit caused the entrance to the river to be forced southwards, a process eventually checked by the building of groynes, the harbour being stabilized in 1566. After the cutting off of the spit at Yarmouth the material south of the cut disappeared, the coast between Gorleston and Corton suffered erosion and a Ness was formed at Lowestoft.

Further south, small nesses have been developed at Covehithe and Thorpe, while at Aldeburgh the largest spit on the east coast—Orford Ness—commences. This has diverted the mouth of the river Alde for a distance of 12 miles south of its original outlet at Aldeburgh (Fig. 16). Behind Orford Ness are salt-marshes which have developed under the protection of the shingle-spit and are comparable with those already mentioned at Blakeney and Scolt Head Island. A similar accumulation extending southwards from Felixstowe was also developed on the north of Harwich Harbour, and tended to block the mouth of the Stour, but further diversion was checked by the building of a jetty across the spit, or the history of the Alde might have been repeated.

Meanwhile, in certain parts of the coast, erosion has been particularly active, and in some places the wastage of the cliffs has been accelerated by landslips. Between Happisburgh and Yarmouth the rate of recession of the cliffs has been estimated at 2 to 3 yds. every year, while at Easton Bavent as much as 10 yds. were lost in one year by the ravages of the sea. Probably the best-known places that have been affected by erosion are Dunwich and Eccles. The former, an important city in the time of Henry II, has now almost disappeared. Eccles has been known as a disappearing area since attention was drawn to it by Lyell in his classic *Principles of Geology* (1839). When the church was built here it was doubtless well protected from the sea, but, as a result of the destruction of the high ground that protected it, in 1839 it was surrounded by blown sand. The sand was steadily swept inland past the church, and the tower, which stood for some years alone on the foreshore, was destroyed during a storm in 1895. Now scarcely a trace is left.

An EXHIBIT illustrating the Geology and Scenery of the district described in this volume is set out on the First Gallery of the Geological Museum, Exhibition Road, S.W.7.

XI. GEOLOGICAL SURVEY MAPS AND MEMOIRS DEALING WITH EAST ANGLIA AND ADJOINING AREAS[1]

Maps

(*a*) **On the Scale of 4 miles to 1 inch:** *colour-printed.*

Sheet 12 (Solid and Drift). Peterborough, Norwich and Yarmouth*.
Sheet 15 (Solid only). Part of Bedfordshire.
Sheet 16 (Solid and Drift). Cambridge, Ipswich.

(*b*) **On the Scale of 1 mile to 1 inch:** [*Old Series: hand-coloured.*

Sheet 46 N.W.—Woburn, &c. Solid.
Sheet 46 N.E.—Biggleswade, &c. Solid or Drift.
Sheet 46 S.W.—Leighton Buzzard, Dunstable, &c. Solid.
Sheet 46 S.E.—Luton, &c. Drift.
Sheet 47.—Part of S. Cambridgeshire and S. Suffolk. Solid or Drift.
Sheet 48 N.W.—Ipswich, Hadleigh, &c. Drift.
Sheet 48 N.E.—S. Suffolk, east of Ipswich. Drift.
Sheet 49 N.W.—Coast of Suffolk, Dunwich—Southwold, &c. Drift.
Sheet 49 S.W.—Coast of Suffolk, North and South of Aldeburgh. Drift.
Sheet 50 N.W.—Diss, Eye, Botesdale, Ixworth. Drift.
Sheet 50 N.E.—Harleston, Halesworth, Westleton, &c. Drift.
Sheet 50 S.W.—Stowmarket, Needham Market. Drift.
Sheet 50 S.E.—Saxmundham, Orford, &c. Drift.
Sheet 51 N.W.—Ely, St. Ives and S. Fenland. Solid or Drift.
Sheet 51 N.E.—Mildenhall, Thetford, &c. Drift.
Sheet 51 S.W.—Cambridge, &c. Solid or Drift.
Sheet 51 S.E.—Newmarket, Bury St. Edmunds. Drift.
Sheet 52 N.W.—Huntingdonshire (small part). Solid.
Sheet 52 N.E.—Huntingdon, &c. Solid.
Sheet 52 S.W.—Harrold, &c. Solid.
Sheet 52 S.E.—St. Neots, Bedford, Potton, &c. Solid.
Sheet 64 (Part). Peterborough. Solid or Drift.
Sheet 65.—Wisbech, King's Lynn, March, Downham Market, Swaffham, Brandon. Drift.
Sheet 66 N.W.—East Dereham, Litcham, &c. Drift.
Sheet 66 N.E.—Norwich, Potter Heigham, &c. Drift.
Sheet 66 S.W.—Wymondham, Hingham, &c. Drift.
Sheet 66 S.E.—Beccles, Bungay, &c. Drift.
Sheet 67 N.W.—Coast from Great Yarmouth to Horsey. Drift.
Sheet 67 S.W.—Lowestoft, and coast south from Yarmouth to near Gisleham. Drift.
Sheet 68 E.—Norfolk Coast from Sheringham to Eccles; Cromer, Mundesley, Aylsham, &c. Drift.
Sheet 68 N.W.—Norfolk Coast from Weybourne to West of Wells. Drift.
Sheet 68 S.W.—Holt, Fakenham, &c. Drift.
Sheet 69.—The Wash, Boston, Hunstanton, &c. Drift.

New Series: hand-coloured:

Sheet 203.—Bedford. Drift.

New Series: colour-printed. Drift.

Sheet 187.—Huntingdon. Drift*.
Sheet 204.—Biggleswade*.
Sheet 205.—Saffron Walden*.
Sheet 206.—Sudbury*.
Sheet 207.—Ipswich*.
Sheet 208.—Woodbridge.
Sheet 225.—Felixstowe.

Memoirs

(*a*) **District Memoirs:**

Cambridge, Neighbourhood of. By W. H. Penning and A. J. Jukes-Browne, 1881.
Fenland. By S. B. J. Skertchly, 1877.
Norfolk and Suffolk, Vertebrata of the Forest Bed Series of. By E. T. Newton, 1882.
Norwich, Neighbourhood of. By H. B. Woodward, 1881.
Rutland and parts of Huntingdon, Cambridge, &c. By J. W. Judd, 1875.

[1] Stocks of Geological Survey Publications were destroyed by enemy action. Those marked with an asterisk are now available.

(*b*) **Sheet Memoirs:**

Memoirs in explanation of the Old Series Maps:

Sheet 47.—Part of Cambridgeshire and S. Suffolk. By W. Whitaker, W. H. Penning and others. 1878.
Sheet 48.—Ipswich, Hadleigh, and Felixstowe. By W. Whitaker, 1885.
Sheet 49.—Southwold, and the Suffolk Coast from Dunwich to Covehithe. By W. Whitaker, 1887.
Sheets 49 (S.) and 50 (S.E.).—Aldeburgh, Framlingham, Orford and Woodbridge. By W. H. Dalton, 1886.
Sheet 50 (N.W.).—Diss, Eye, Botesdale and Ixworth. By F. J. Bennett, 1884.
Sheet 50 (N.E.).—Halesworth and Harleston. By W. Whitaker and W. H. Dalton, 1887.
Sheet 50 (S.W.).—Stowmarket. By W. Whitaker and others, 1881.
Sheet 51 (N.E. and part of N.W.).—Cambridge and Suffolk, parts of (Ely, Mildenhall and Thetford). By W. Whitaker, H. B. Woodward and A. J. Jukes-Browne, 1891.
Sheet 51 (S.E.).—Bury St. Edmunds and Newmarket. By F. J. Bennett and J. H. Blake, 1886.
Sheet 65.—Norfolk, south-western, and northern Cambridgeshire. By W. Whitaker, S. B. J. Skertchly and A. J. Jukes-Browne, 1893.
Sheet 66 (N.W.).—East Dereham. By J. H. Blake, 1888.
Sheet 66 (S.W.).—Attleborough, Watton and Wymondham. By F. J. Bennett, 1884.
Sheet 67.—Yarmouth and Lowestoft. By J. H. Blake, 1890.
Sheet 68 (N.W. and S.W.).—Fakenham, Wells and Holt. By H. B. Woodward, 1884.
Sheet 69.—Borders of the Wash, including Boston and Hunstanton. By W. Whitaker and A. J. Jukes-Browne, 1899.

Memoirs in explanation of the New Series Maps:—

Sheet 205.—Saffron Walden. By H. J. Osborne White, 1932.
Sheet 206.—Sudbury. By P. G. H. Boswell, 1929.
Sheet 207.—Ipswich. By P. G. H. Boswell, 1927.
Sheets 208 and 225.—Woodbridge, Felixstowe and Orford. By P. G. H. Boswell, 1928.

(*c*) **Water Supply Memoirs:**

Bedfordshire and Northamptonshire. 1909.
Cambridgeshire, Huntingdonshire and Rutland. 1922.
Norfolk. 1921.
Suffolk. 1906.
See also ' Wartime Pamphlets ' below.

(*d*) **General Memoirs:**

The Pliocene Deposits of Britain. By C. Reid, 1890.
The Vertebrata of the Pliocene Deposits of Britain. By E. T. Newton, 1891.
Gun Flints: the Age of Palaeolithic Man, &c. By S. B. J. Skertchly, 1879.
Cretaceous Rocks of Britain:
  Vol. I.—The Gault and Upper Greensand of England. By A. J. Jukes-Browne, with contributions by W. Hill, 1900.
  Vol. II.—The Lower and Middle Chalk of England. By A. J. Jukes-Browne, with contributions by W. Hill, 1903.
  Vol. III.—The Upper Chalk of England. By A. J. Jukes-Browne, with contributions by W. Hill, 1904.
Jurassic Rocks of Britain:
  Vol. IV.—The Lower Oolitic Rocks of England (Yorkshire excepted). By H. B. Woodward, 1894.
  Vol. V.—The Middle and Upper Oolitic Rocks of England (Yorkshire excepted). By H. B. Woodward, 1895.

(*e*) **Wartime Pamphlets:**

No. 20.—Water Supply from Underground Sources of the Cambridge-Ipswich District (Quarter-Inch Geological Sheet 16). By A. W. Woodland.
  Parts I to IX. Well Catalogues. 1942-5.
  Part X. General Discussion. 1946.

PHOTOGRAPHS

A series of photographs illustrative of the geology of the area (of which Plates II-VIII are examples) are deposited for public reference in the Library of the Geological Survey. Copies of these photographs and lantern slides are supplied at standard rates.

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